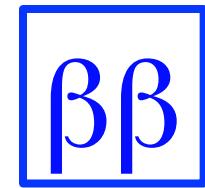


The MAJORANA Project

a status report

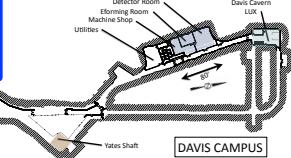


Outline



Science

Underground
Laboratory



Shield



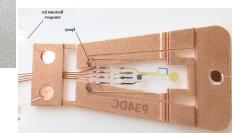
Monoliths



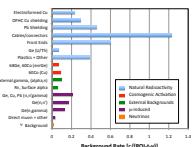
Strings



Detectors



Small
Parts



Background



What is $\beta\beta$?

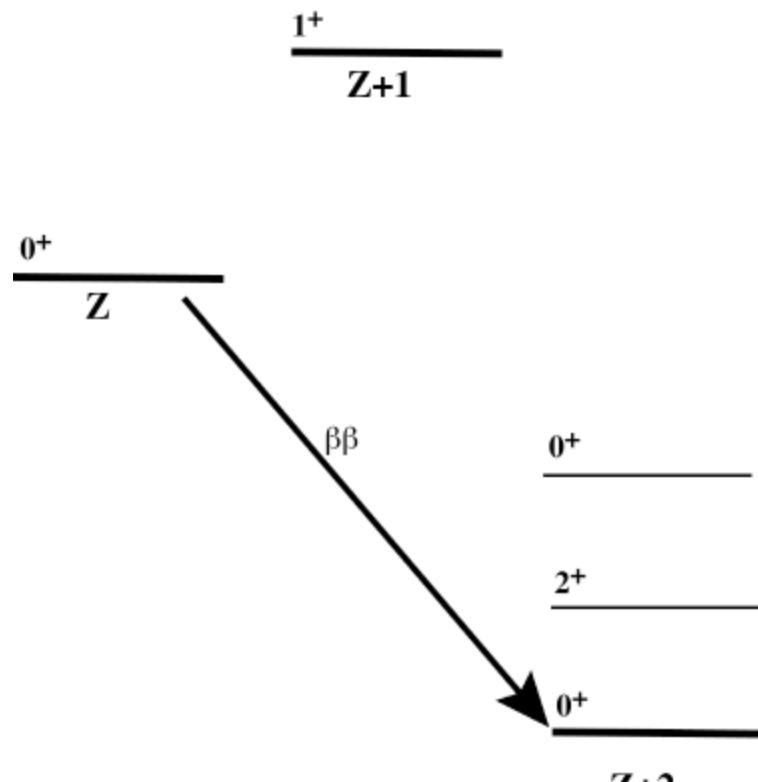


Fig. from arXiv:0708.1033

FNAL, May 2015

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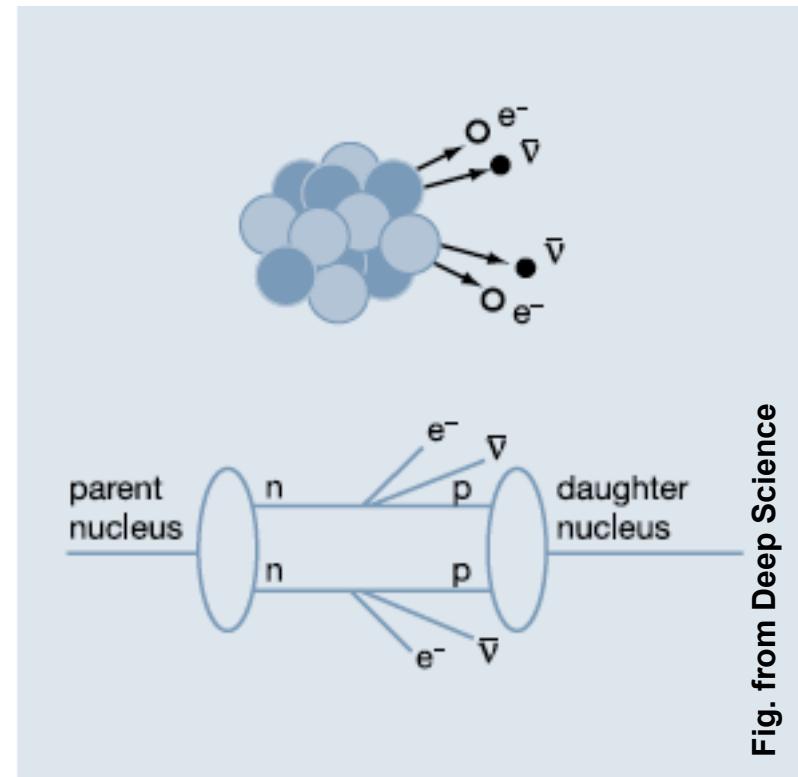


Fig. from Deep Science

What is $\beta\beta$?

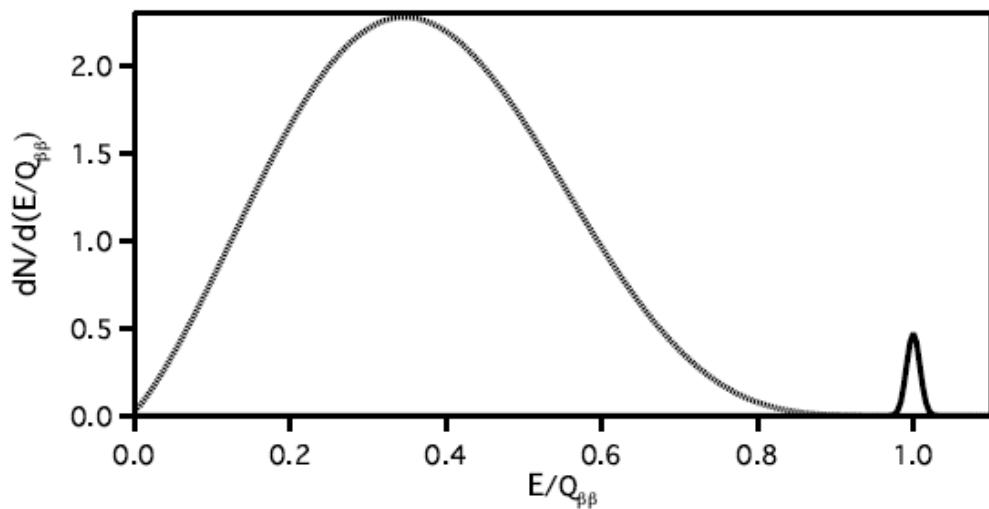
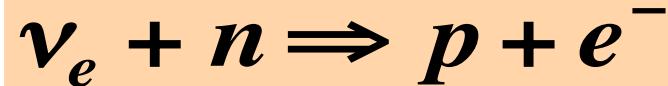
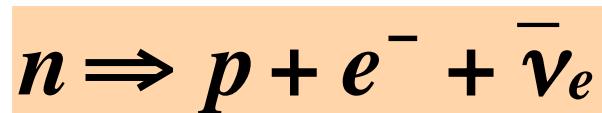


Fig. from arXiv:0708.1033

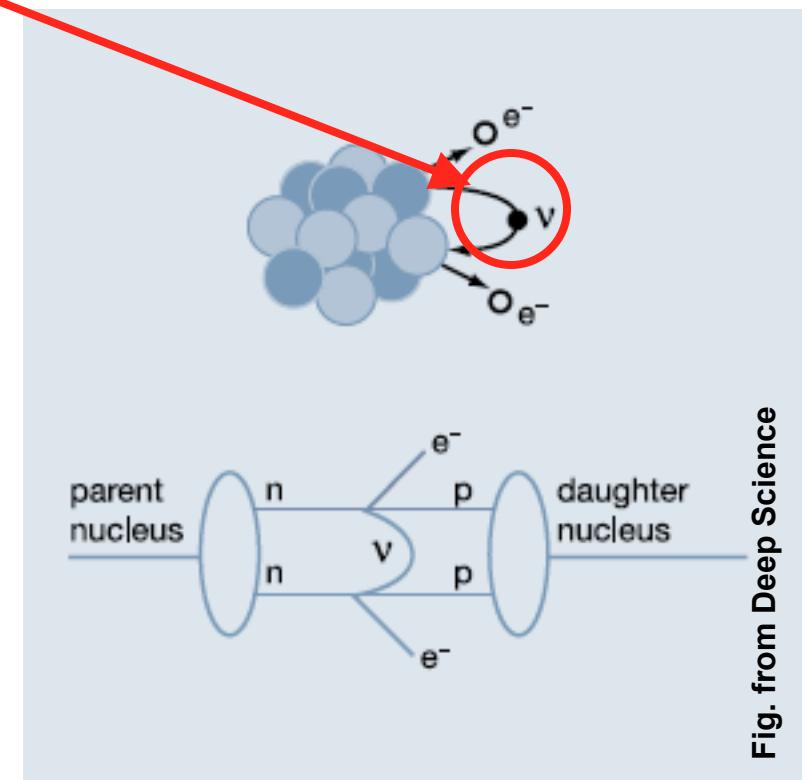


Fig. from Deep Science

$\beta\beta$ Decay Rates

$$\Gamma_{2\nu} = G_{2\nu} |M_{2\nu}|^2$$

$$\Gamma_{0\nu} = G_{0\nu} |M_{0\nu}|^2 m_\nu^2$$

G are calculable phase space factors.

$$G_{0\nu} \sim Q^5$$

$|M|$ are nuclear physics matrix elements.

Hard to calculate.

m_ν is where the interesting physics lies.

What about mixing, m_ν & $\beta\beta(0\nu)$?

No mixing: $\langle m_{\beta\beta} \rangle = m_{\nu_e} = m_1$

$$\langle m_{\beta\beta} \rangle = \sum_{i=1}^3 |U_{ei}|^2 m_i \varepsilon_i$$

virtual ν
exchange

$\varepsilon = \pm 1$, CP cons.

Compare to β decay result:

$$\langle m_\beta \rangle = \sqrt{\sum_{i=1}^3 |U_{ei}|^2 m_i^2}$$

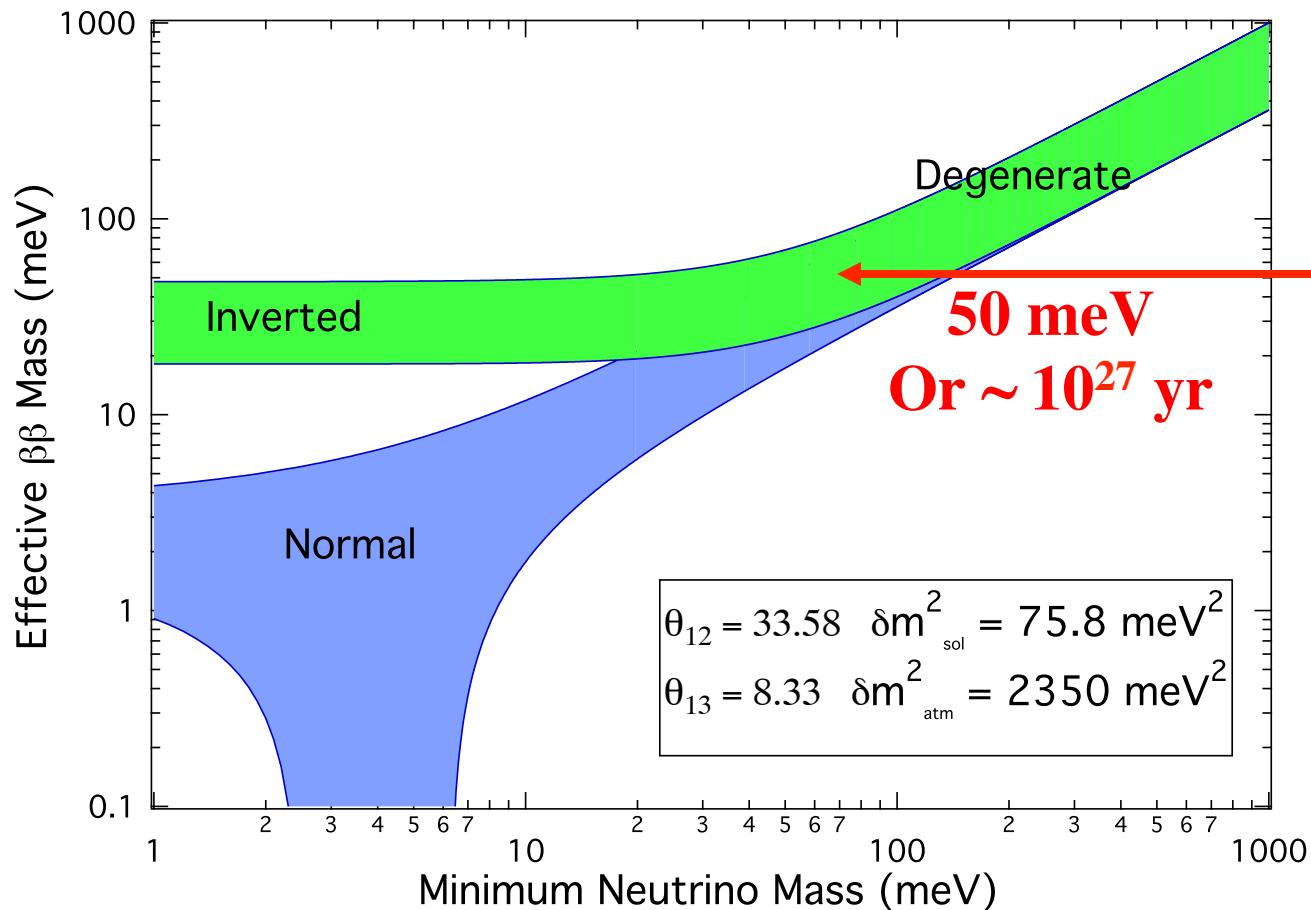
real ν
emission

Compare to cosmology:

$$\sum = \sum m_i$$

$\beta\beta$ Sensitivity

(mixing parameters from arXiv:1106.6028)



Even a null result will constrain the possible mass spectrum possibilities!

A $m_{\beta\beta}$ limit of ~ 15 meV would disfavor Majorana neutrinos in an inverted hierarchy.

$\beta\beta$ and the neutrino

- $\beta\beta(0\nu)$ decay rate proportional to neutrino mass
 - Most sensitive laboratory technique (if Majorana particle)
- Decay can only occur if Lepton number conservation is violated
 - Leptogenesis?
- Decay can only occur if neutrinos are massive Majorana particles
 - Critical for understanding incorporation of mass into standard model
 - **$\beta\beta$ is only practical experimental technique to answer this question**
- Fundamental nuclear/particle physics process

$\beta\beta$ History

- $\beta\beta(2\nu)$ rate first calculated by Maria Goeppert-Mayer in 1935.
- First observed directly in 1987.
- Why did this take so long? Background

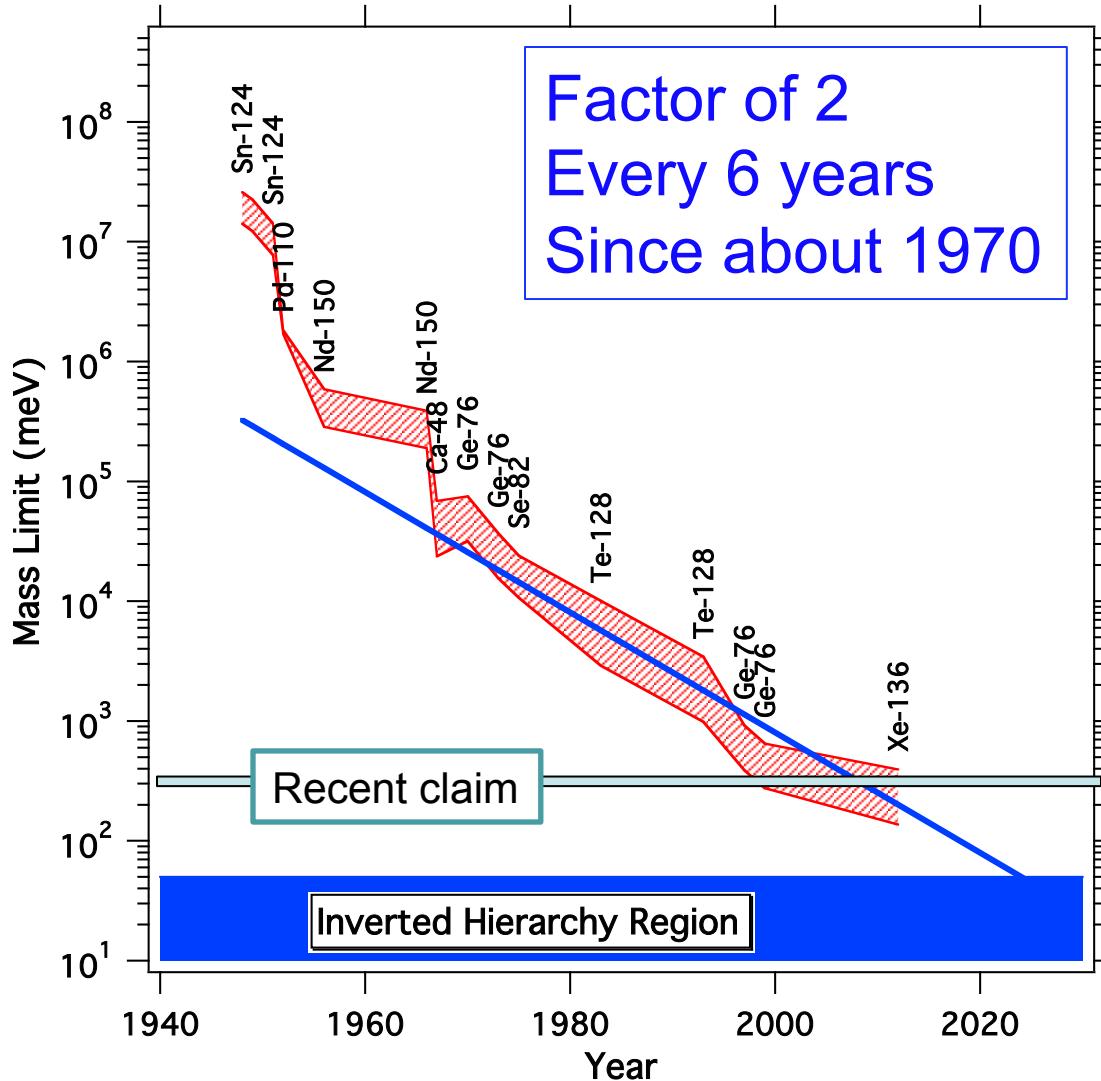
$$\tau_{1/2}(U, Th) \sim T_{universe}$$

$$\tau_{1/2}(\beta\beta(2\nu)) \sim 10^{10} T_{universe}$$

- But next we want to look for a process with:

$$\tau_{1/2}(\beta\beta(0\nu)) \sim 10^{17} T_{universe}$$

$\beta\beta$ History



Historically, there are > 100 experimental limits on $T_{1/2}$ of the $0\nu\beta\beta$ decay. Here are the records expressed as limits on $\langle m_{\beta\beta} \rangle$ using a range of nuclear matrix elements. Note the approximate linear slope vs time on such semilog plot.

Although Xe has a lead in the mass limit, Ge does a better job excluding the claim.

An Ideal Experiment

Maximize Rate/Minimize Background

$$\langle m_{\beta\beta} \rangle \propto \left(\frac{b\Delta E}{MT_{live}} \right)^{\frac{1}{4}}$$

- Large Exposure (~ 10 t-y)
- Low Background (< 1 count/t-y)
- Large Q value, fast $\beta\beta(0\nu)$
- Good source radiopurity
- Demonstrated technology
- Ease of operation
- Source = detector
- Good energy resolution
- Slow $\beta\beta(2\nu)$ rate
- Identify daughter in real time
- Event reconstruction

Experimental Parameters

$$\langle m_{\beta\beta} \rangle \leq (2.50 \times 10^{-5} \text{ meV}) \sqrt{\frac{W}{fx\varepsilon G_{0\nu} |M_{0\nu}|^2}} \left[\frac{b\Delta E}{MT} \right]^{\frac{1}{4}}$$

- **W – molecular weight of source**
- **f – isotopic abundance**
- **x – number of bb isotopes per molecule**
- **ε – detector efficiency**
- **$G_{0\nu}$ – decay phase space**
- **$|M_{0\nu}|$ - matrix element**
- **b – background in counts/keV-kg-y**
- **ΔE – energy window in keV**
- **M – mass of source in kg**
- **T – counting time in years**

- When comparing isotopes, don't forget W, favors low A. $G_{0\nu}$ favors high A.
- QRPA has more A dependence than SM.

Isotope	$\sqrt{W/(G_{0\nu} M_{0\nu} ^2)} \times 10^7$
Ge	2.4(QRPA) 4.7(SM)
TeO_2	1.9(QRPA) 3.1(SM)
Xe	2.4(QRPA) 3.3(SM)

Isotope Choice

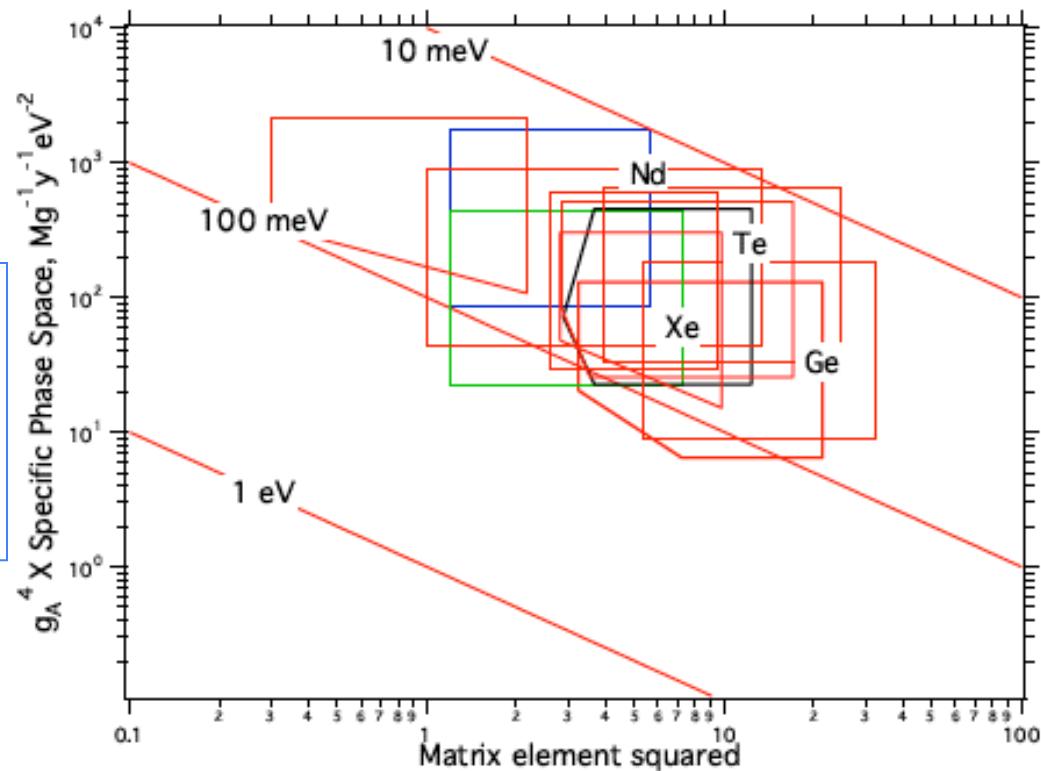
$$MT = (2.50 \times 10^{-5} \text{ meV})^2 \frac{NW}{fx\epsilon G_{0\nu}} \left(\frac{1}{\langle m_{\beta\beta} \rangle M_{0\nu} g_A^2} \right)^2$$

$N = \sqrt{B} = \sqrt{b\Delta EMT}$ background limited

Many authors ignore:
 f, x, ϵ, W
when comparing isotopes

All isotopes are roughly comparable.

Robertson Mod. Phys. Lett. A,
28 (2013) 1350021

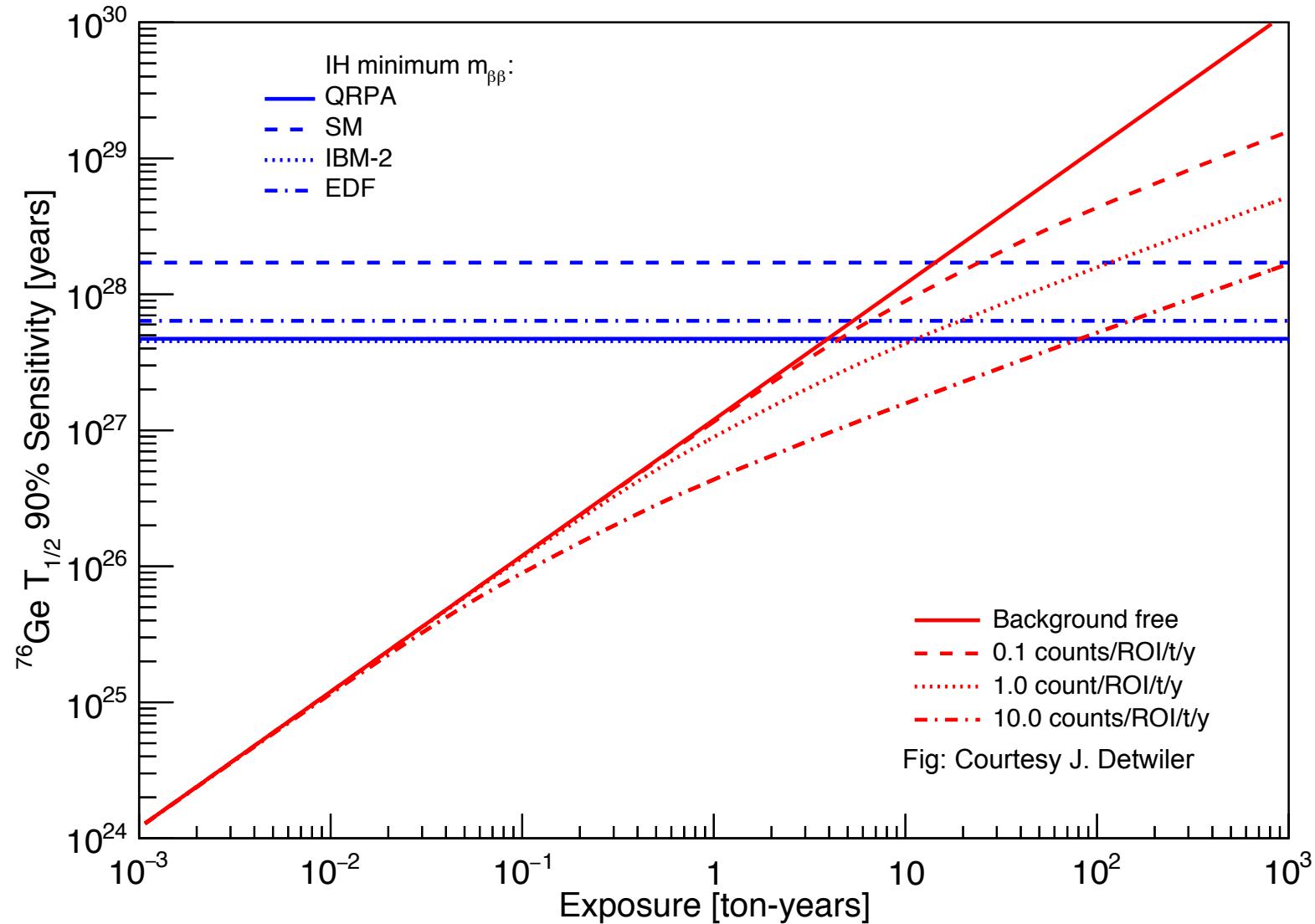


Signal:Background $\sim 1:1$

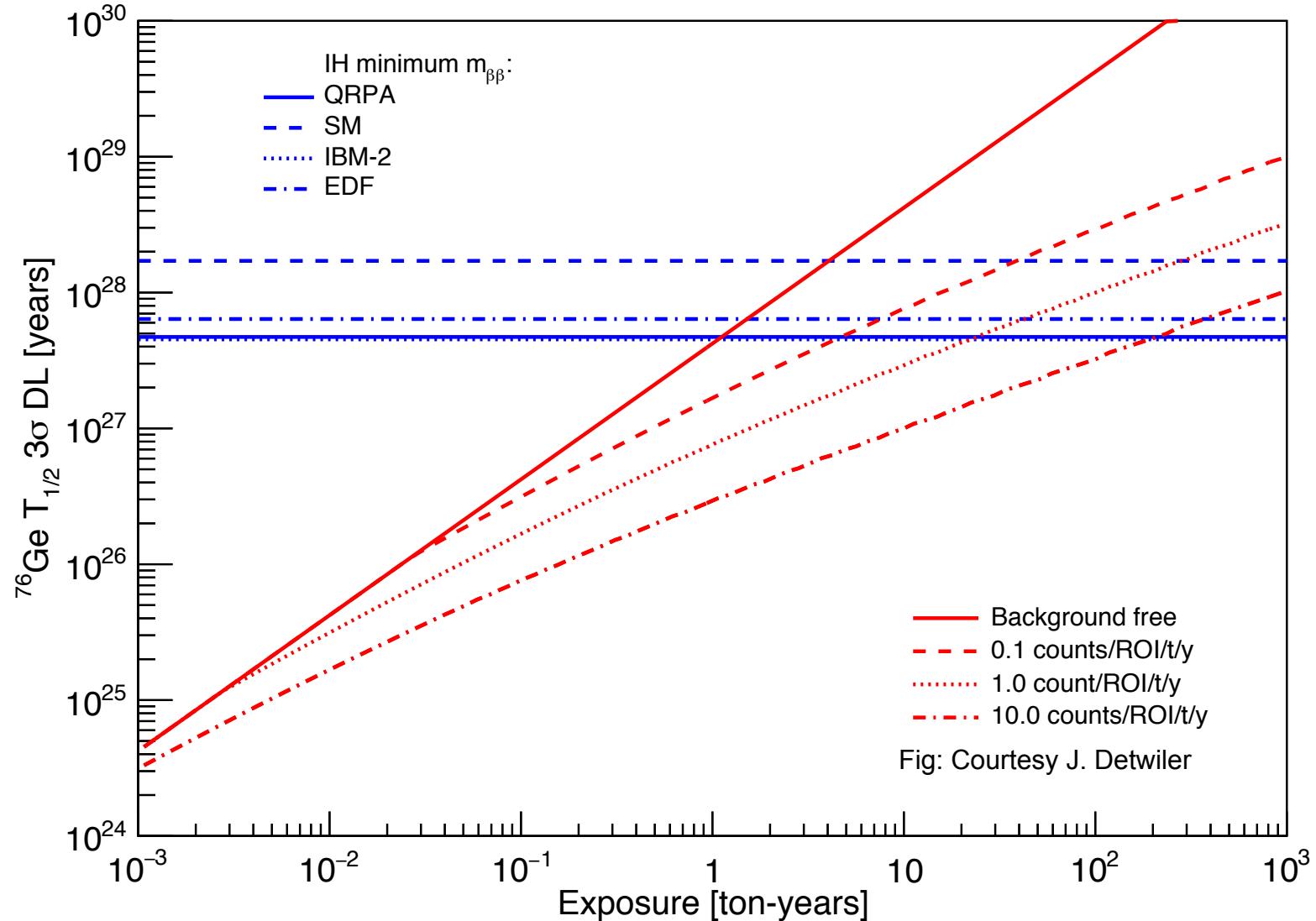
Background is a key issue in $\beta\beta$

Half life (years)	~Signal (cnts/ton-year)	~Neutrino mass scale (meV)	
10^{25}	530	400	Degenerate
5×10^{26}	10	100	
5×10^{27}	To reach atmospheric scale need BG on order $1/t\text{-}y.$	40	Atmospheric
$>10^{29}$		<10	Solar

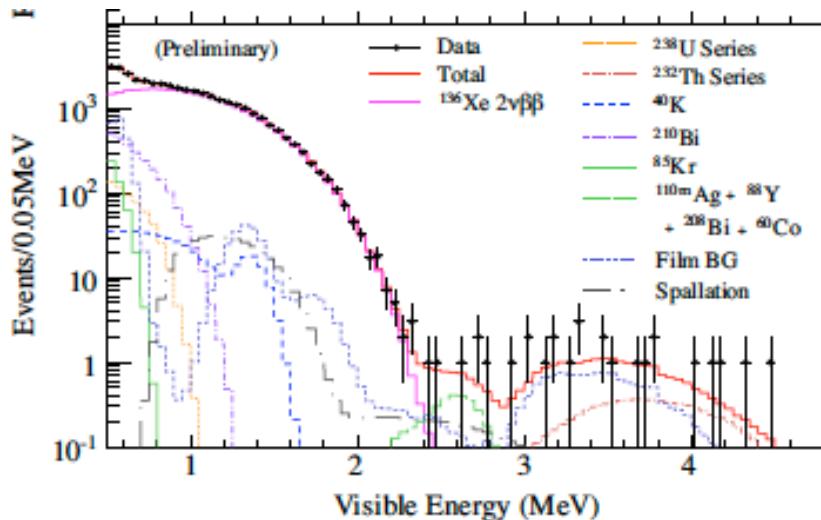
Sensitivity, Background and Exposure



Discovery, Background and Exposure

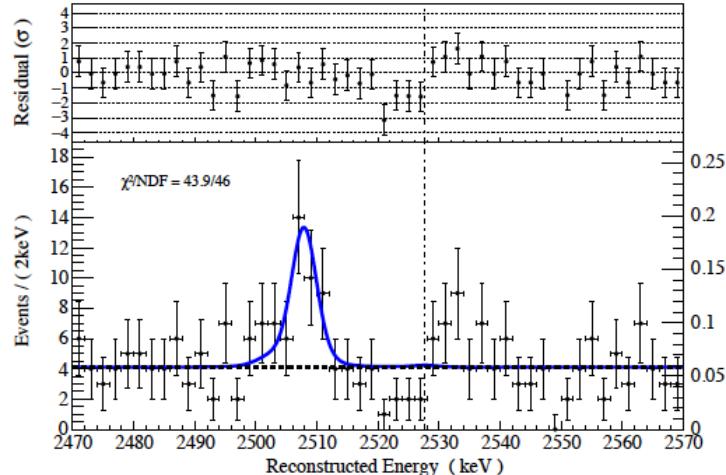


Background in Recent Experiments



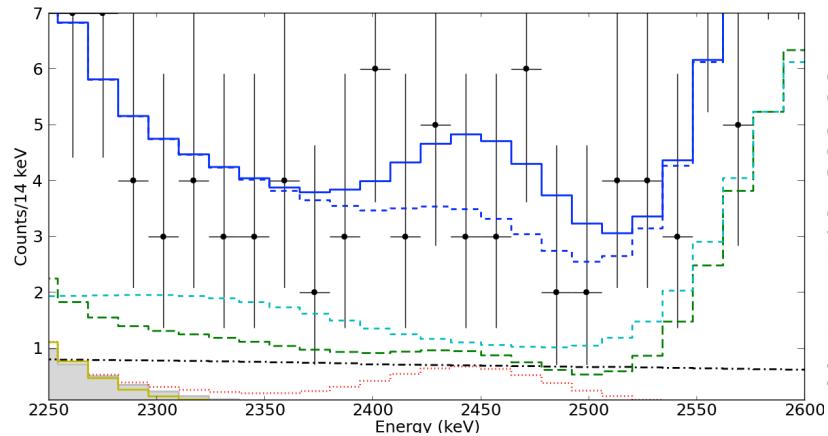
KamLAND-Zen: 210 c/ROI/t(Xe)/y
 EXO-200: 130 c/ROI/t/y

arXiv:1409.0077



CUORE-0: 300 c/ROI/t/y
 GERDA: 40 c/ROI/t/y

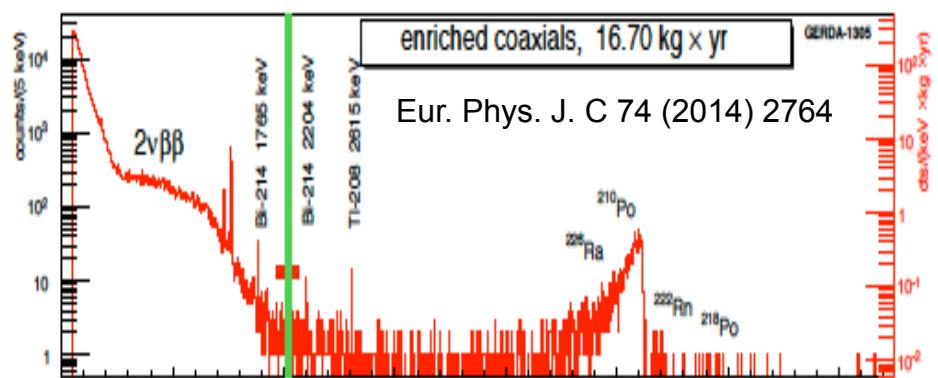
arXiv:1504.02454



FNAL, May 2015

Nature 510, 229-234

Steve Elliott



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Background State-of-the-Art Summary

Experiment	Background (cnts/ ROI-t-y)	Width (1 FWHM)
IGEX	960 (400 with PSD)	4 keV ROI
Heid-Moscow	440 (50 with PSD)	4 keV ROI
CUORE-0	300	6 keV ROI
GERDA	40	4 keV ROI
EXO-200	130	88 keV ROI
KamLAND-Zen	~4 (~210 per t(Xe))	Width not explicitly given

Background is per tonne of material – big difference for KamLAND-Zen.
The arithmetic is mine. Errors are my fault.

Experiments are nearing 100 meV in sensitivity.

	Mass	Run Plan
CUORE	~200 kg	2016
EXO-200	~100 kg	2011
GERDA I/II	~34 kg	2011/2015
KamLAND-Zen	~300 kg	2012
MAJORANA	~30 kg	2015
NEXT	~10 kg	2016
SNO+	~120 kg	2016
SuperNEMO Dem.	~7 kg	2015

Good guess
that we'll reach
about 100 meV
in the 2016/17
time frame.

Ton-scale
projects might
be starting by
2020.

NSAC Subcommittee (highlights added)

The Subcommittee recommends the following guidelines be used in the development and consideration of future proposals for the next generation experiments:

- 1.) **Discovery potential**: Favor approaches that have a credible path toward reaching 3σ sensitivity to the effective Majorana neutrino mass parameter $m_{\beta\beta}=15 \text{ meV}$ **within 10 years** of counting, assuming the lower matrix element values among viable nuclear structure model calculations.
- 2.) **Staging**: Given the risks and level of resources required, support for **one or more intermediate stages** along the maximum discovery potential path may be the optimal approach.
- 3.) **Standard of proof**: Each next-generation experiment worldwide must be capable of providing, on its own, compelling evidence of the **validity of a possible non-null signal**.
- 4.) **Continuing R&D**: The demands on background reduction are so stringent that modest scope **demonstration projects for promising new approaches to background suppression** or sensitivity enhancement should be pursued with high priority, in parallel with or in combination with ongoing NLDBD searches.
- 5.) **International Collaboration**: Given the desirability of establishing a signal in multiple isotopes and the likely cost of these experiments, it is important to coordinate with other countries and funding agencies to develop an **international approach**.
- 6.) **Timeliness**: It is desirable to push for results from at least the first stage of a next-generation effort on **time scales competitive** with other international double beta decay efforts and with independent experiments aiming to pin down the neutrino mass hierarchy.

Discovery vs. Measurement

a future decision point

Expt. Size: up to 10 kg

Sensitivity: ~1 eV

~10 $\beta\beta(2\nu)$ measurements

Expt. Size: 100-200 kg

Several experiments

Program to measure
rate in several isotopes

Expt. Size: 30-200 kg

Sensitivity: ~100 meV

Quasi-degenerate

~8-10 expts. worldwide

Expt. Size: few T

>3 experiments

Program to measure
rate in several isotopes
Kinematic meas.

**MAJORANA
DEMONSTRATOR**

Expt. Size: ~1T

~3 expts.

Sensitivity: 15 meV

Atmos. scale

Expt. Size: > 10T

~3 expts.

Sens.: 5 meV

Solar scale

1985- Present

2007-2015

2015- 2025

Future

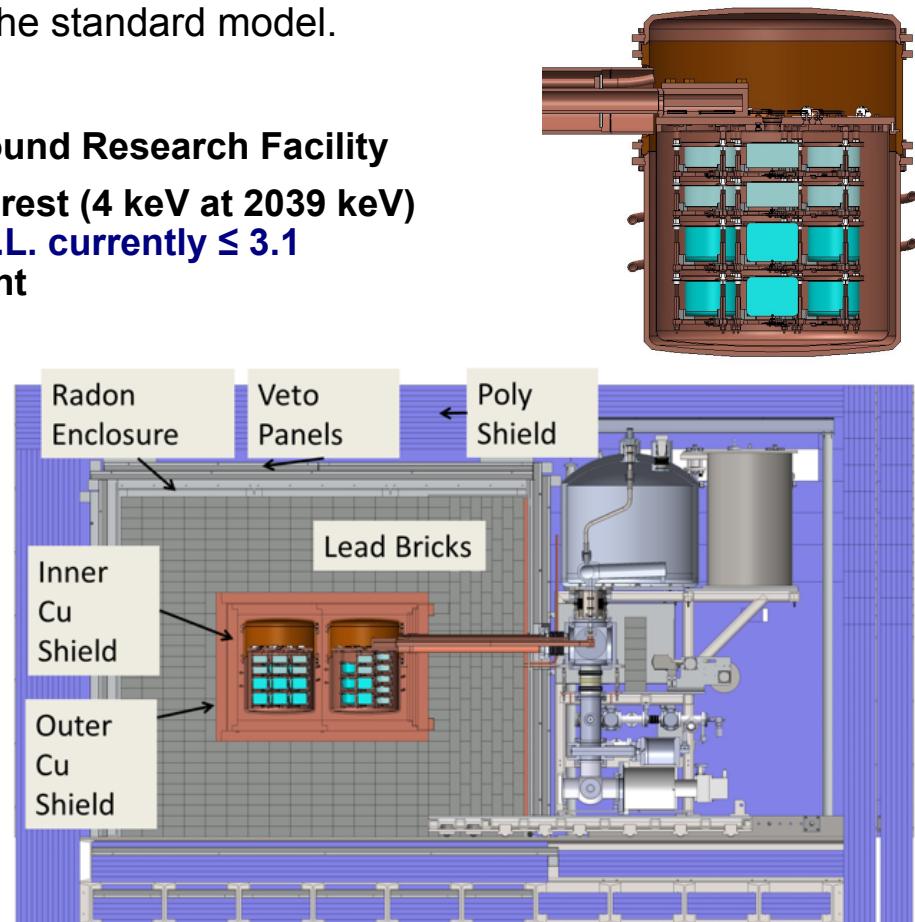
The MAJORANA DEMONSTRATOR



Funded by DOE Office of Nuclear Physics and NSF Particle Astrophysics,
with additional contributions from international collaborators.

- Goals:**
- Demonstrate backgrounds low enough to justify building a tonne scale experiment.
 - Establish feasibility to construct & field modular arrays of Ge detectors.
 - Searches for additional physics beyond the standard model.

- Located underground at 4850' Sanford Underground Research Facility
- Background Goal in the $0\nu\beta\beta$ peak region of interest (4 keV at 2039 keV)
3 counts/ROI/t/y (after analysis cuts) Assay U.L. currently ≤ 3.1
scales to 1 count/ROI/t/y for a tonne experiment
- 40-kg of Ge detectors
 - 30 kg of 87% enriched ^{76}Ge crystals
 - 10 kg of $^{\text{nat}}\text{Ge}$
 - Detector Technology: P-type, point-contact.
- 2 independent cryostats
 - ultra-clean, electroformed Cu
 - 20 kg of detectors per cryostat
 - naturally scalable
- Compact Shield
 - low-background passive Cu and Pb shield with active muon veto



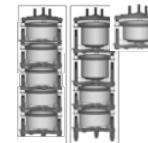
MAJORANA DEMONSTRATOR Implementation



Three Steps

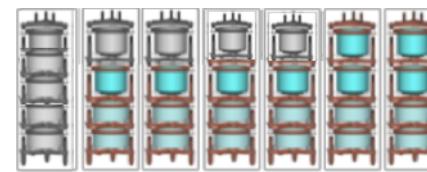
Prototype cryostat: 7.0 kg (10) ^{nat}Ge

Same design as Modules 1 and 2, but fabricated using OFHC Cu Components



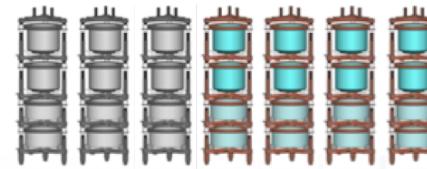
June 2014

**Module 1: 16.8 kg (20) ^{enr}Ge
5.7 kg (9) ^{nat}Ge**

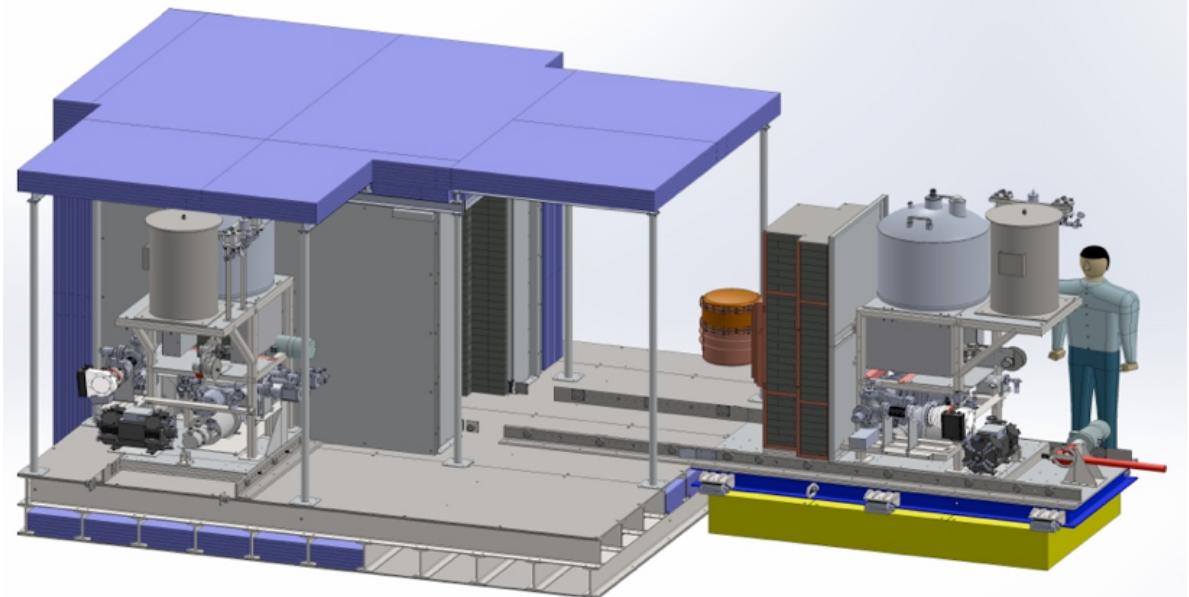
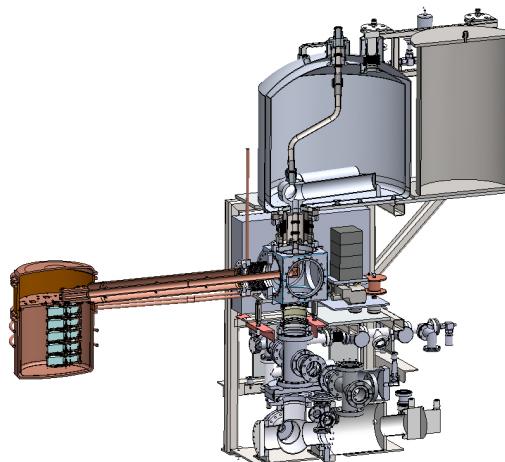


May 2015

**Module 2: 12.6 kg (14) ^{enr}Ge
9.4 kg (15) ^{nat}Ge**

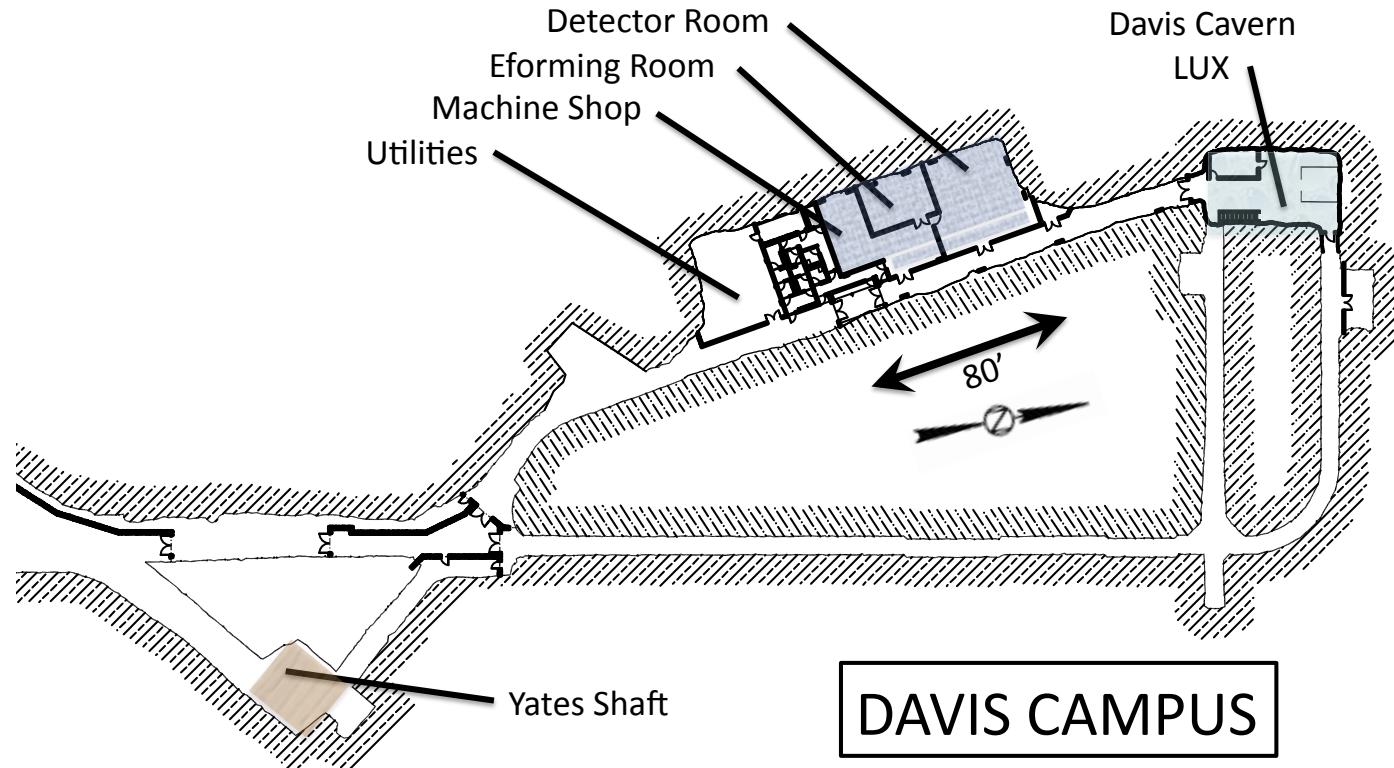


End 2015

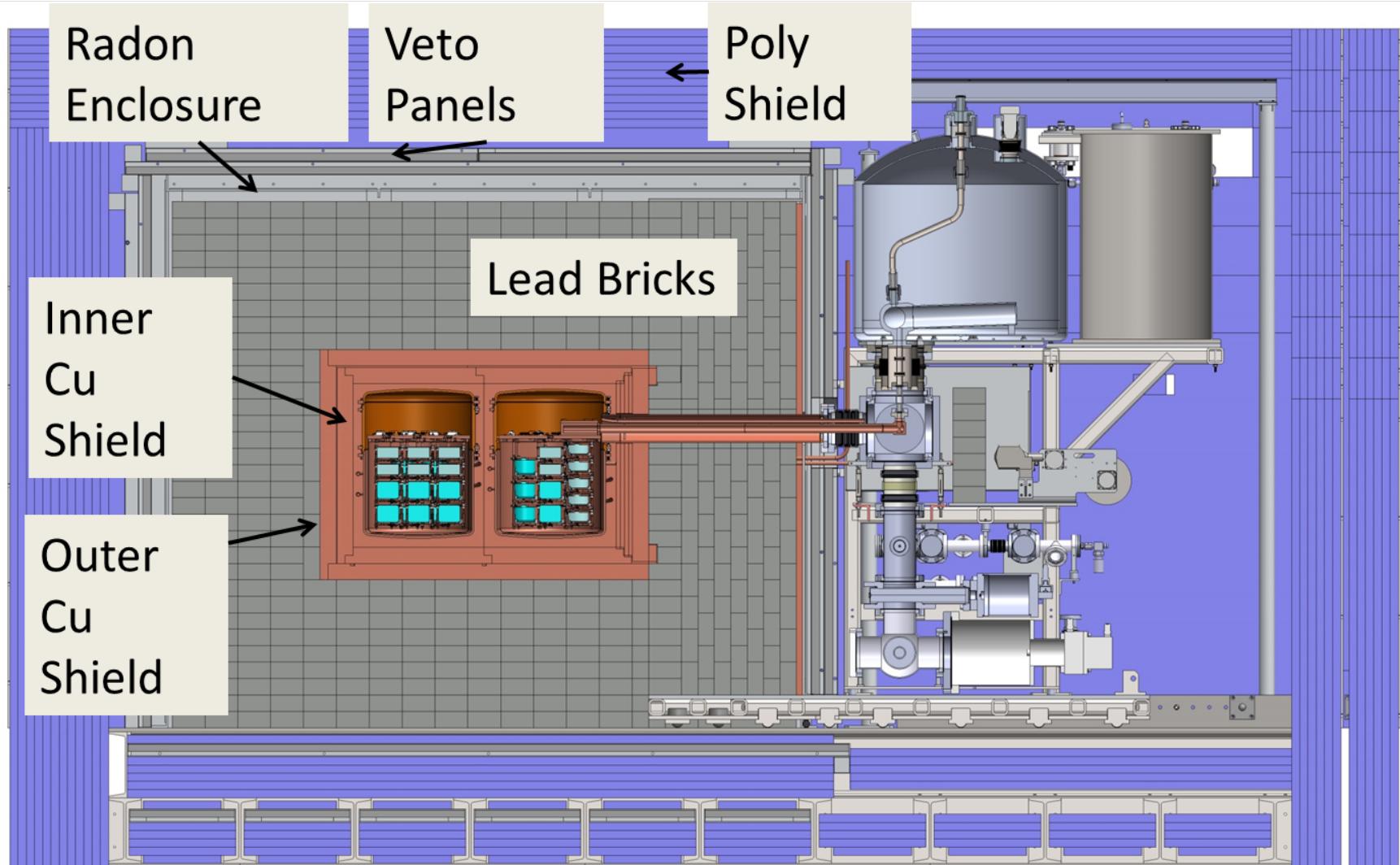


FNAL, May 2015

Underground Laboratory



Apparatus Overview





The Shield

Note keyed structure of shield



- Pb shield constructed
- Outer Cu shield layer installed
- Rn exclusion box installed
- Poly layers being installed
- Hovair in-use underground
- Most veto panels operational
- Calibration system demonstrated



The Shield

Note keyed structure of shield

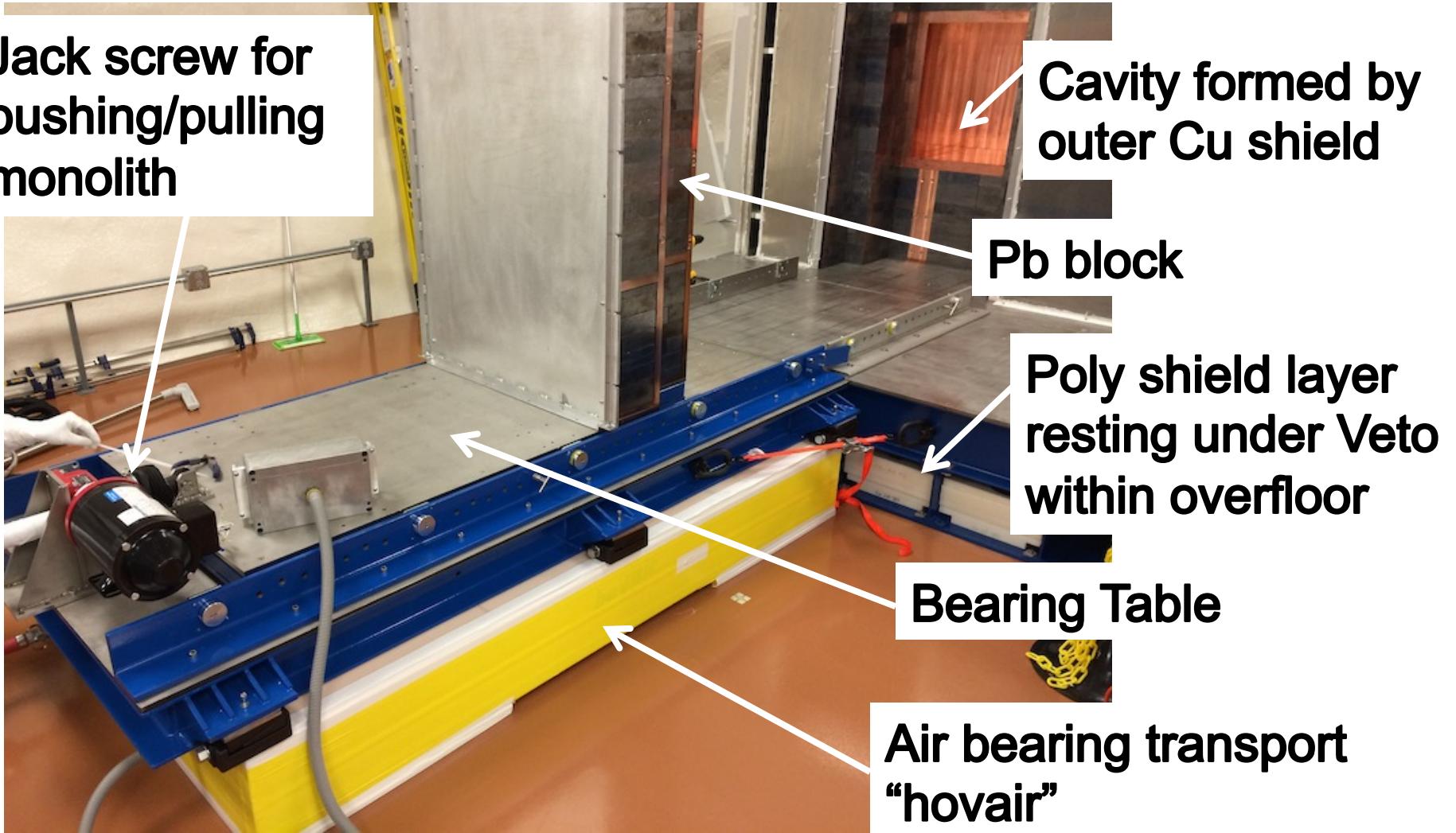


- Pb shield constructed
- Outer Cu shield layer installed
- Rn exclusion box installed
- Poly layers being installed
- Hovair in-use underground
- Most veto panels operational
- Calibration system demonstrated

Blank Monolith, when running only one cryostat of detectors



Jack screw for
pushing/pulling
monolith



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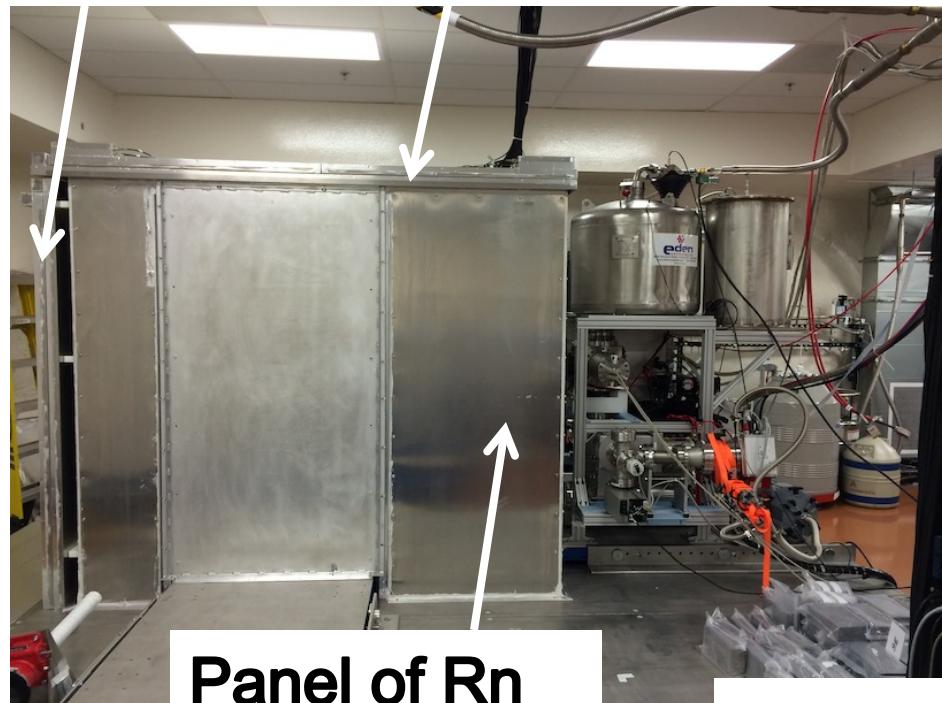
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Shield Details



Side Veto



Panel of Rn
exclusion box

Upper Veto

Prototype Module
Cryostat

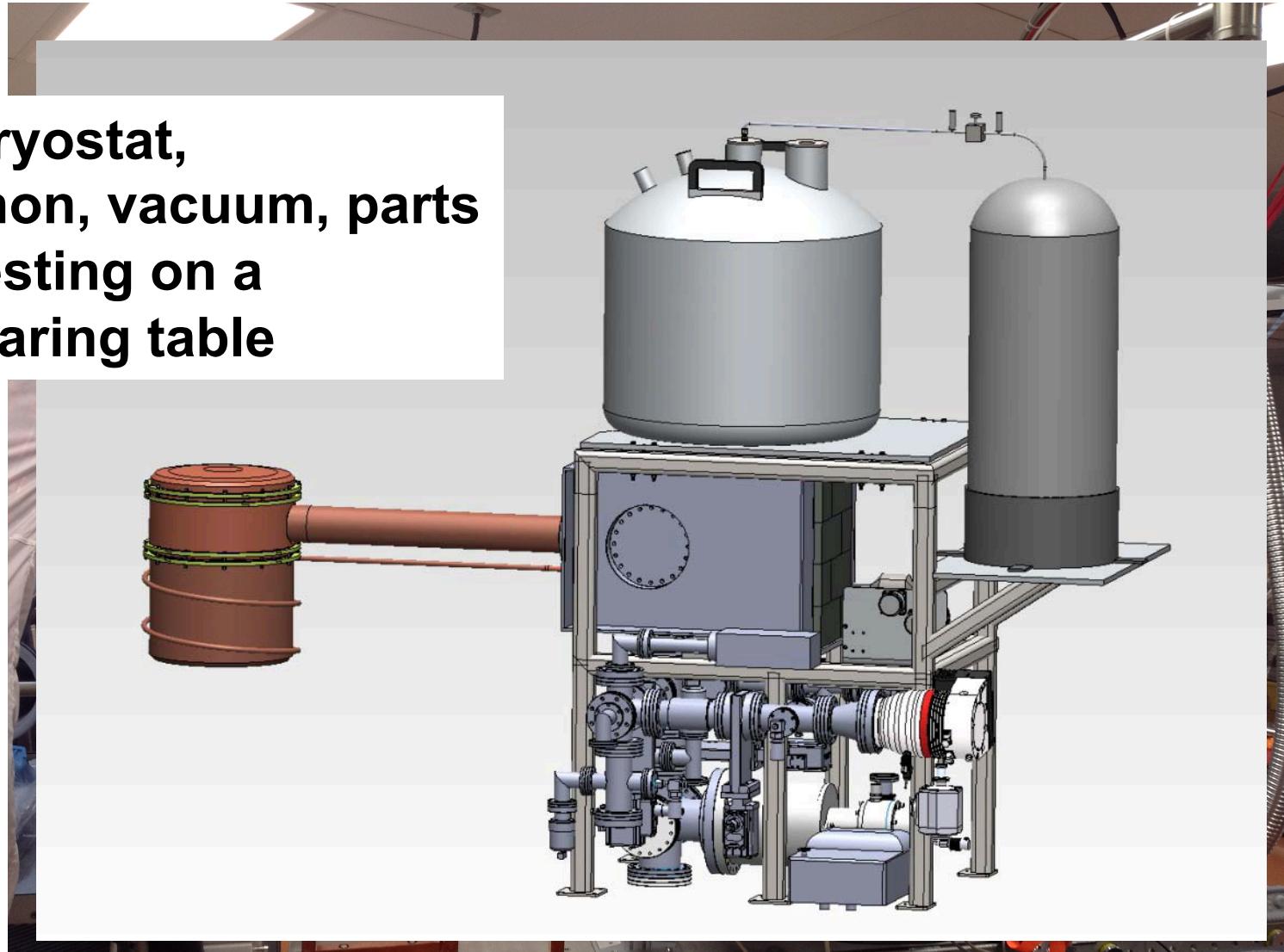


Keyed Pb Stack

Modules



**Module = Cryostat,
thermosyphon, vacuum, parts
of shield, resting on a
movable bearing table**



Modules



FNAL, May 2015

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Modules

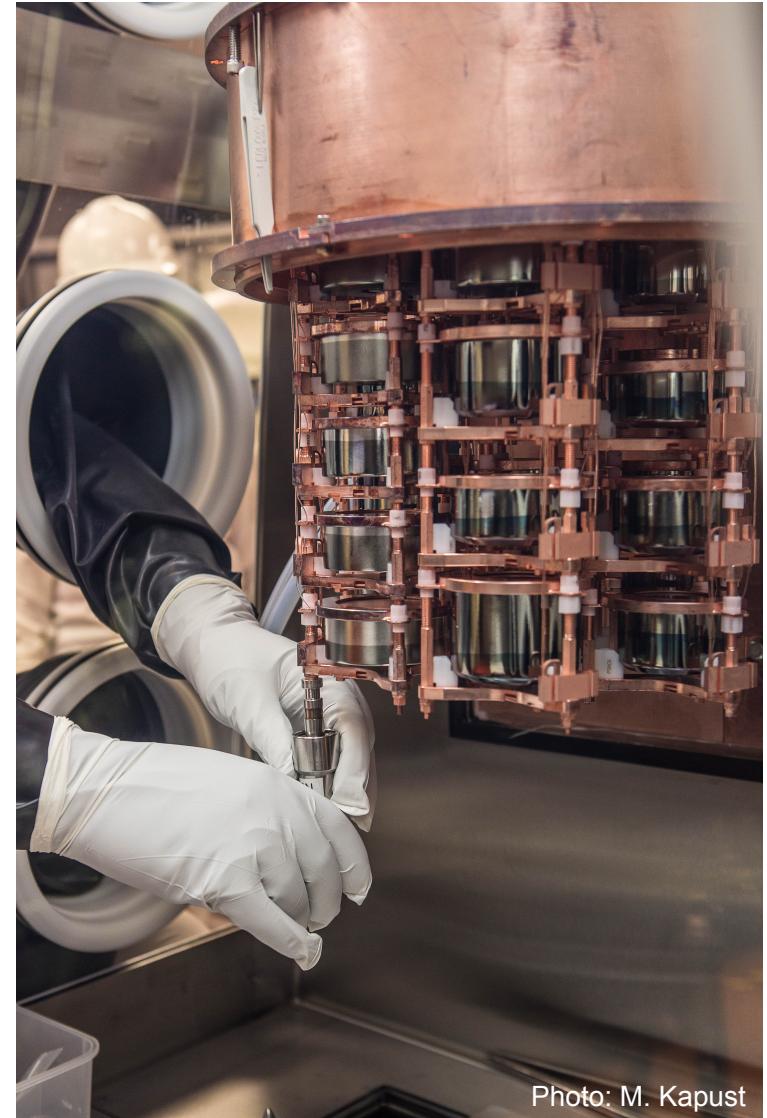


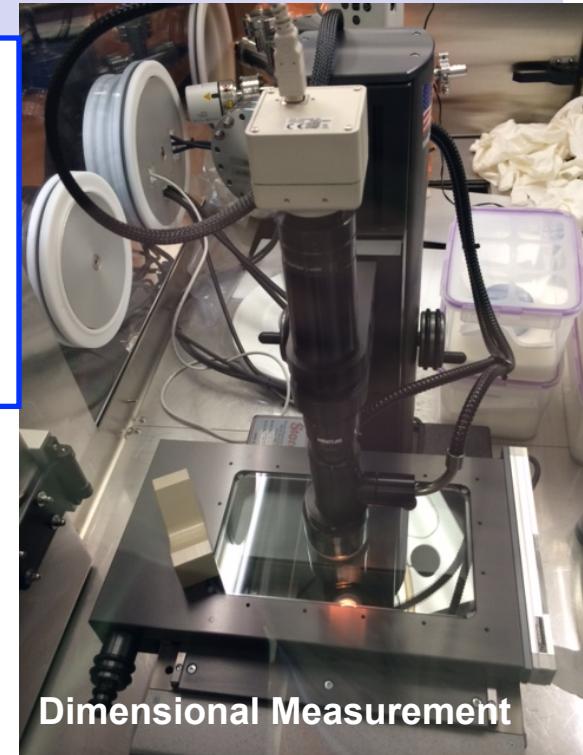
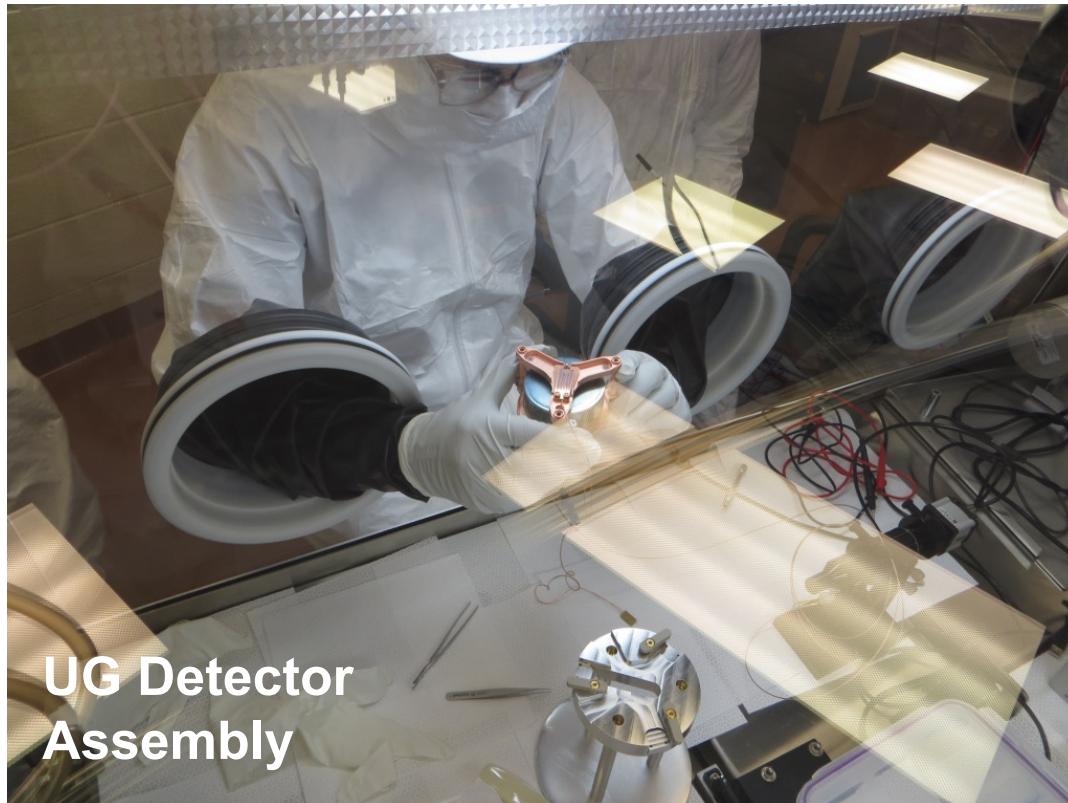
Photo: M. Kapust

- Prototype cryostat operating, over 100 d live.
- Thermosyphon, vacuum system operating.
- Pictured cryostat with enriched detectors will be sited inside shield during May 2015.
- Parts and material tracking in place.
- Clean machining implemented underground.



Detectors

- ORTEC selected for enriched detectors.
- 30 Enriched detectors at SURF 25.2 kg, 87% ^{76}Ge
- Up to an additional 5 kg of enriched detector expected during May 2015. 2 kg UG at ORNL
- 20 kg of modified natural-Ge BEGe (Canberra) detectors in hand (33 detectors UG).

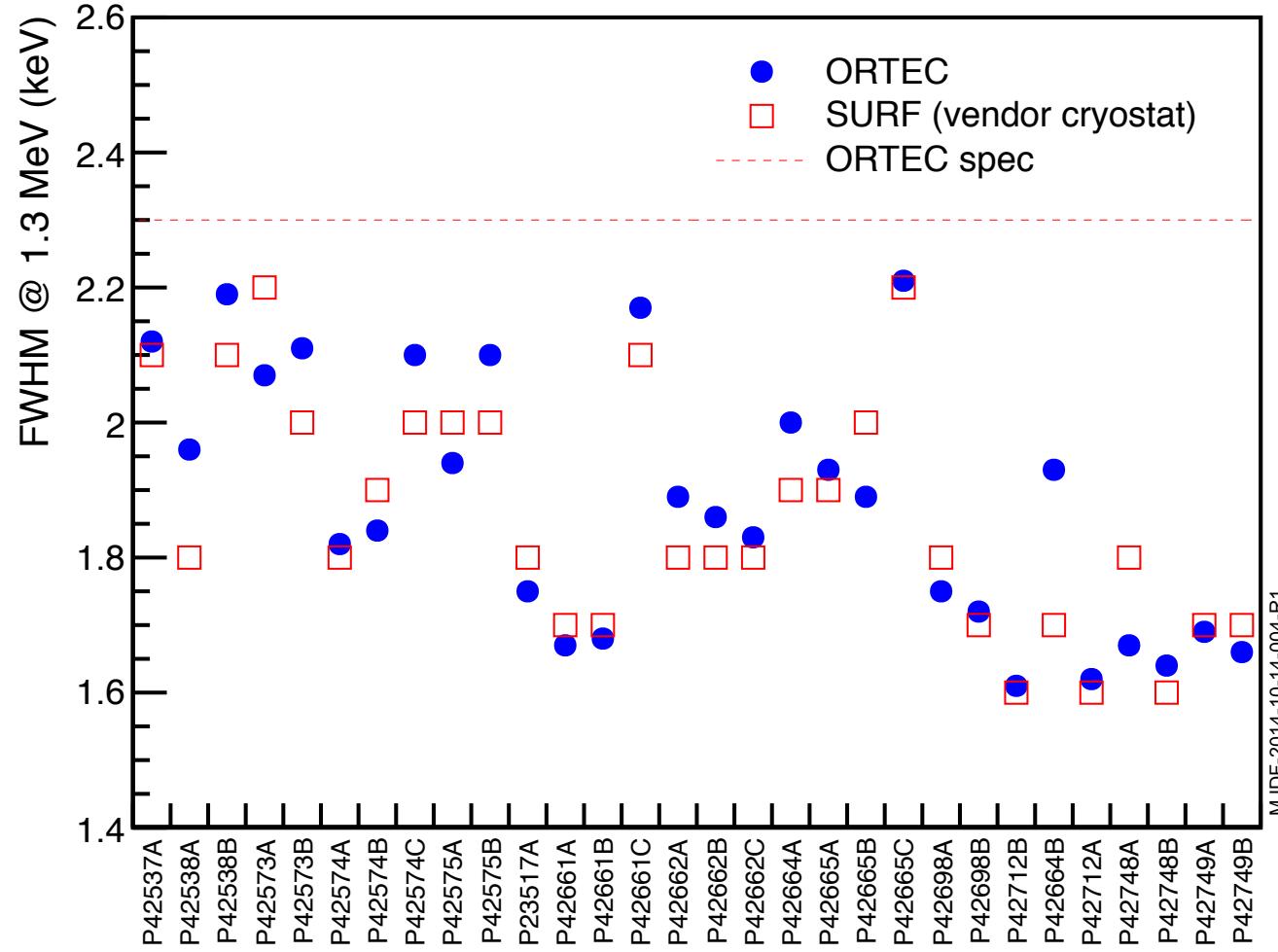


- All detector related assembly performed in N_2 purged gloveboxes.
- All detectors' dimensions recorded by optical reader.



Enriched Detector Performance

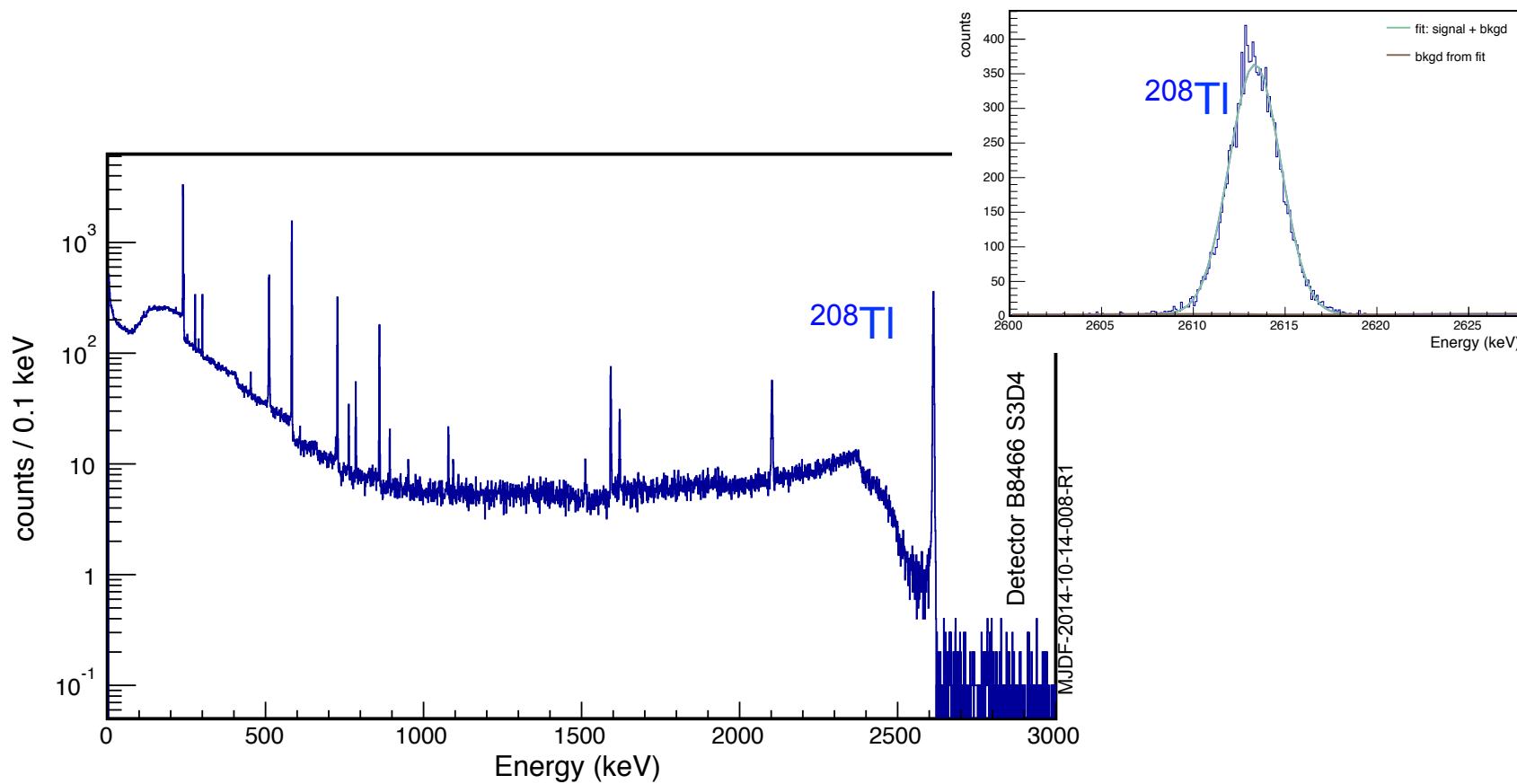
Comparison of measurements done at ORTEC and SURF within the vendor cryostat. All are better than specification.



^{228}Th Calibration Spectrum of Prototype Module Detector



One detector spectrum within a string mounted in the prototype cryostat and inside shield. FWHM 3.2 keV at 2.6 MeV.

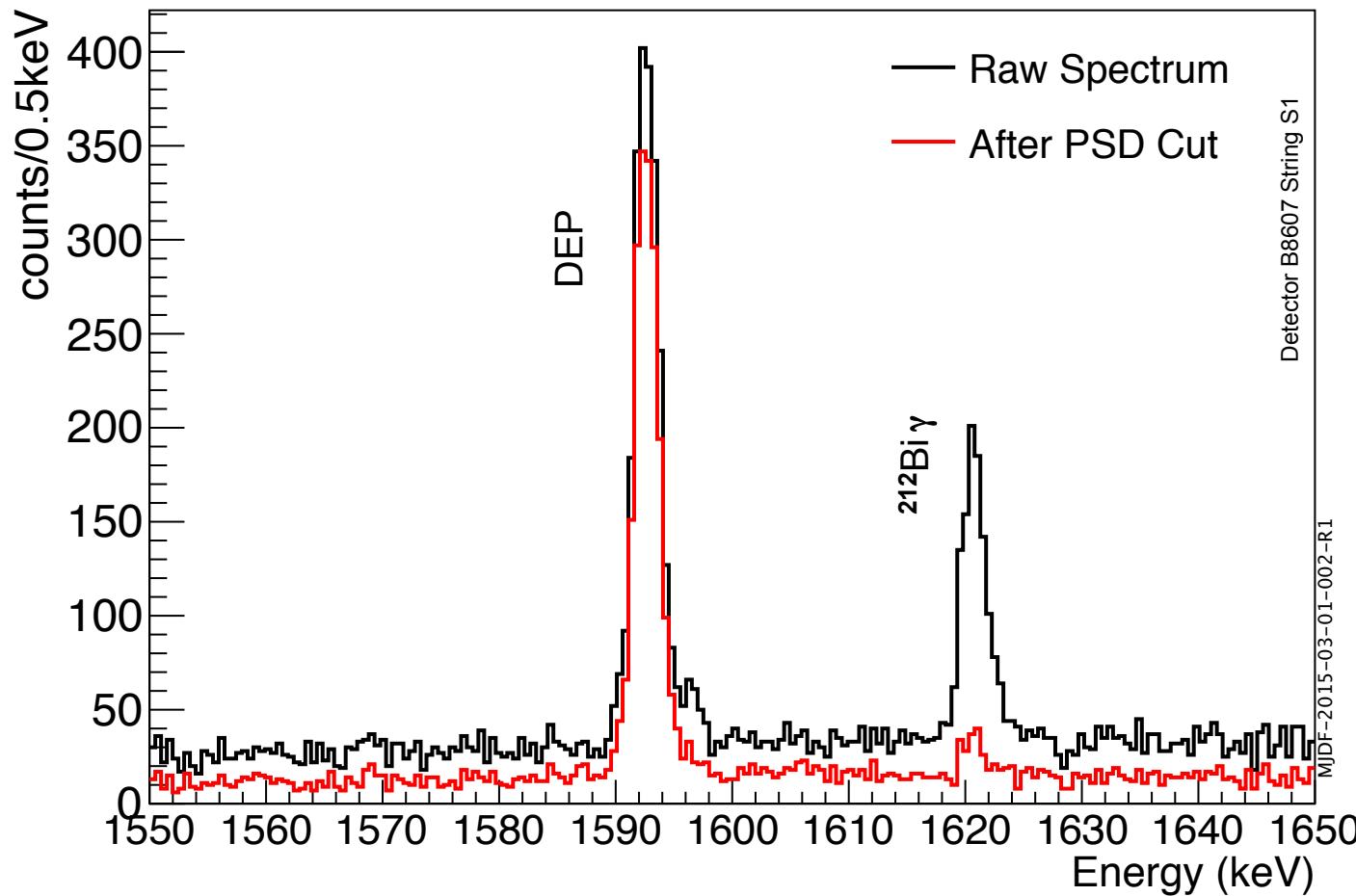




Pulse Shape Discrimination: A/E

Natural BEGe detector in Prototype Cryostat

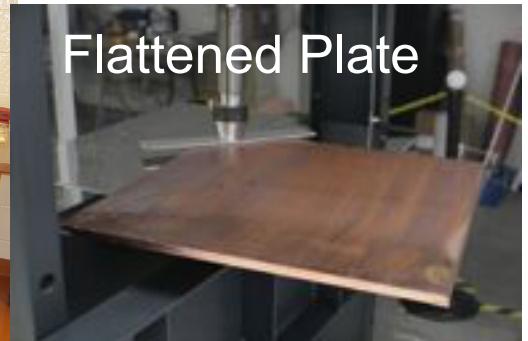
B8466



Electroforming



- Eforming at PNNL and at 4850' at SURF
- Eforming complete in May 2015
- Machine shop operational



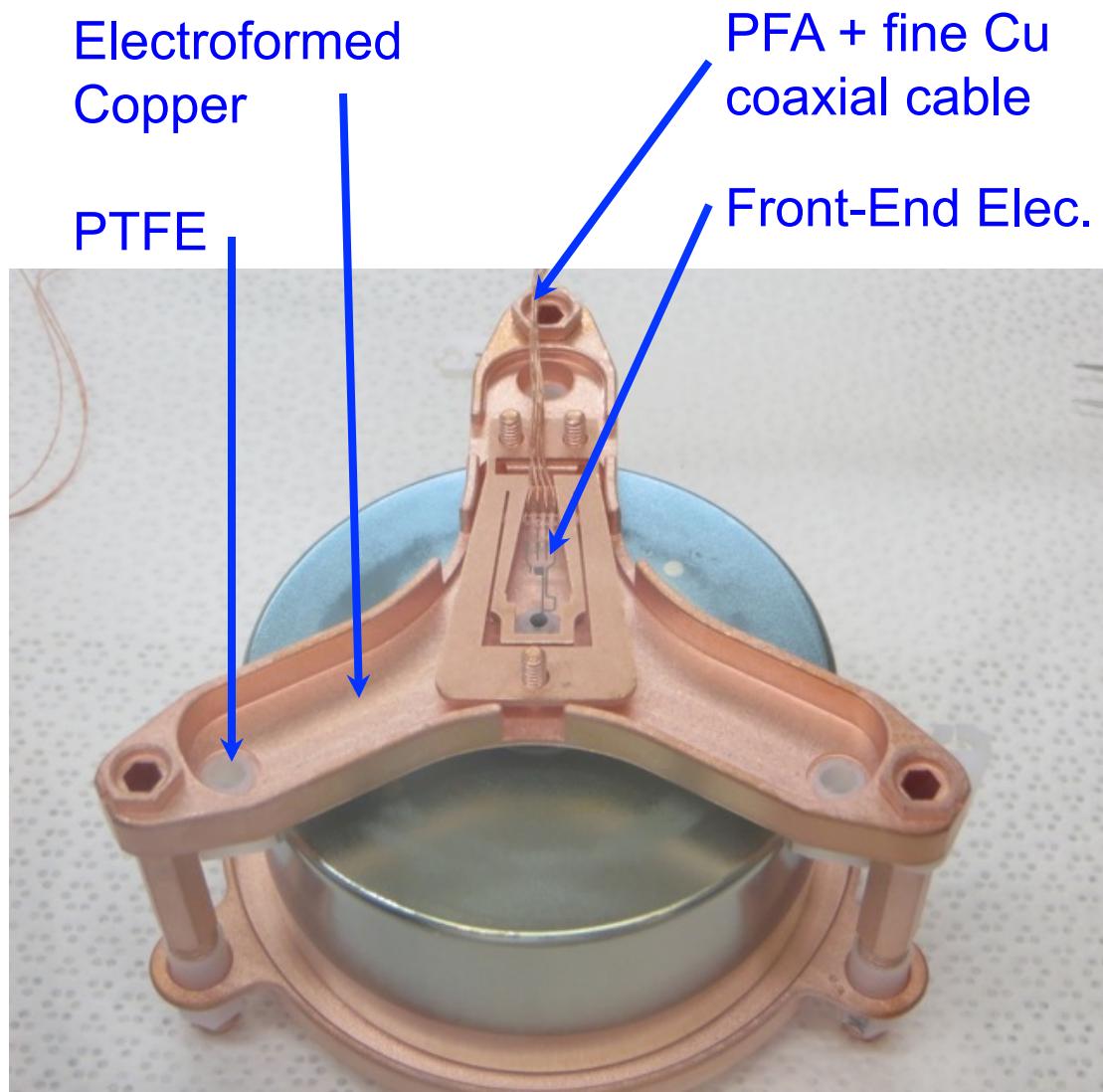
Steve Elliott



Electroformed Parts Stored in Nitrogen

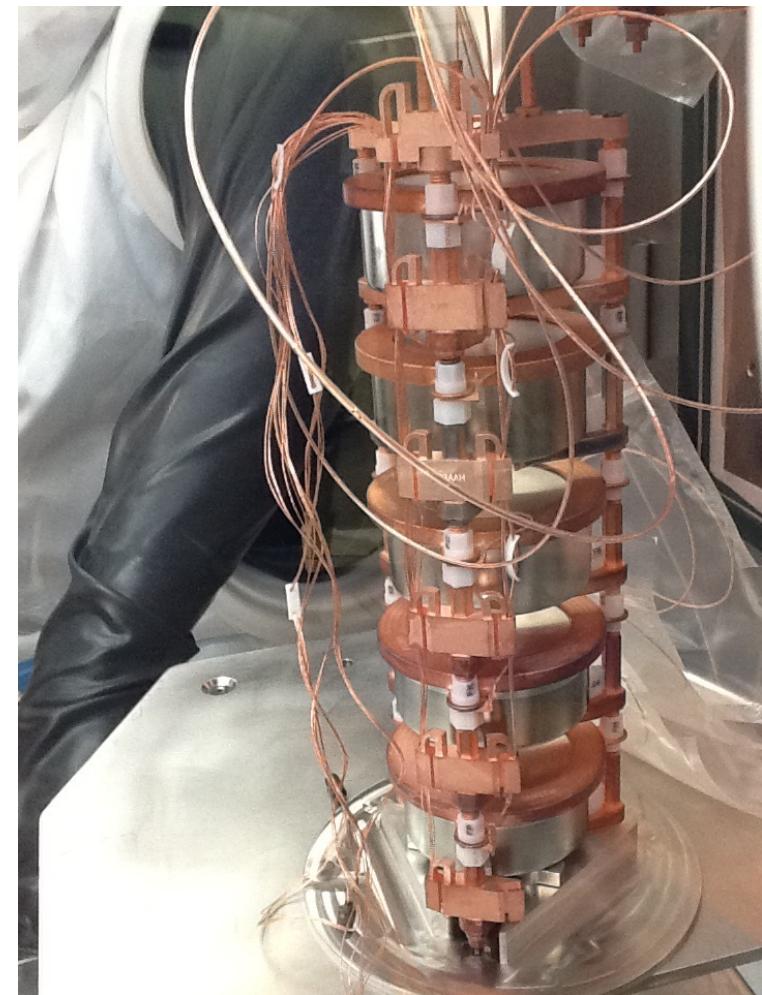


Assembled Detector Unit and String



FNAL, May 2015

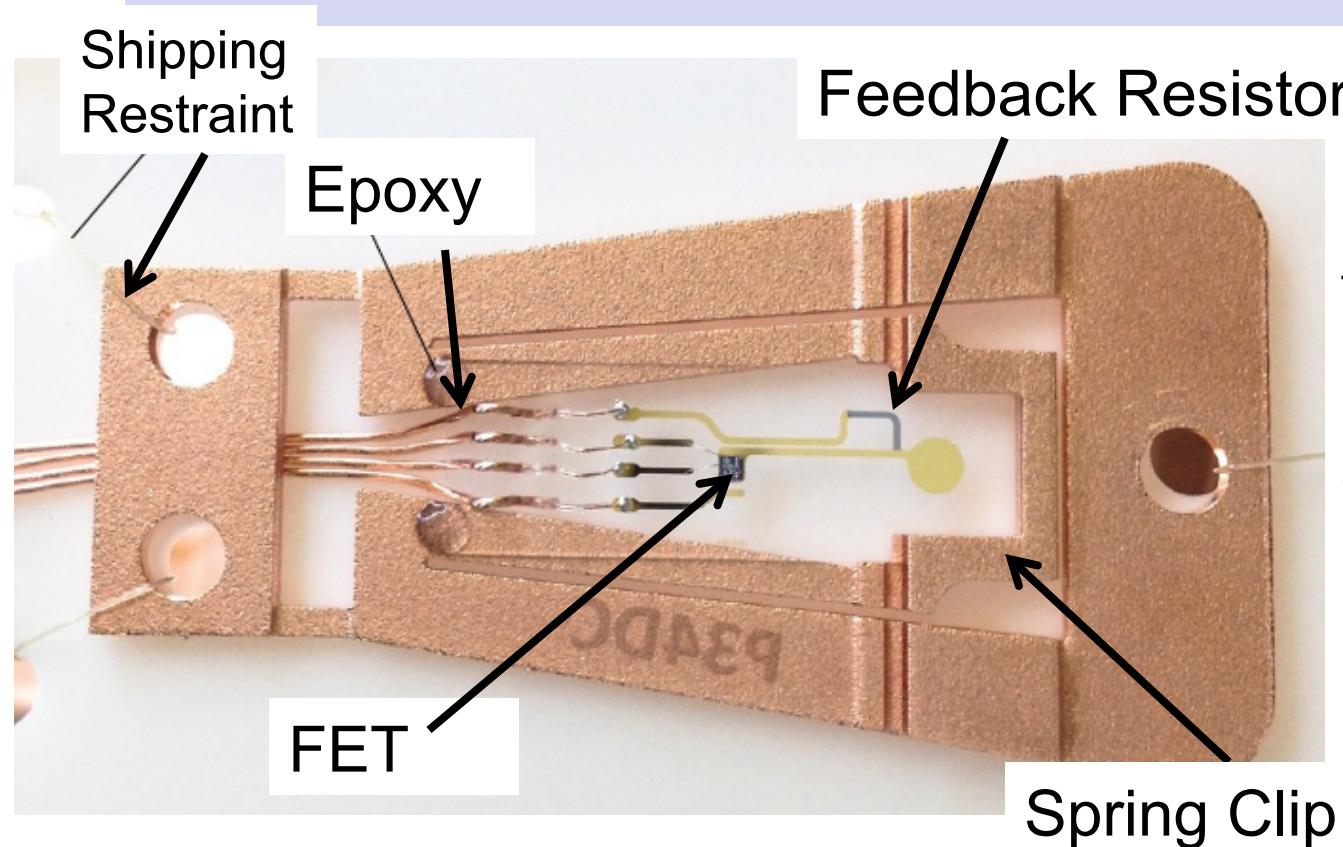
Steve Elliott



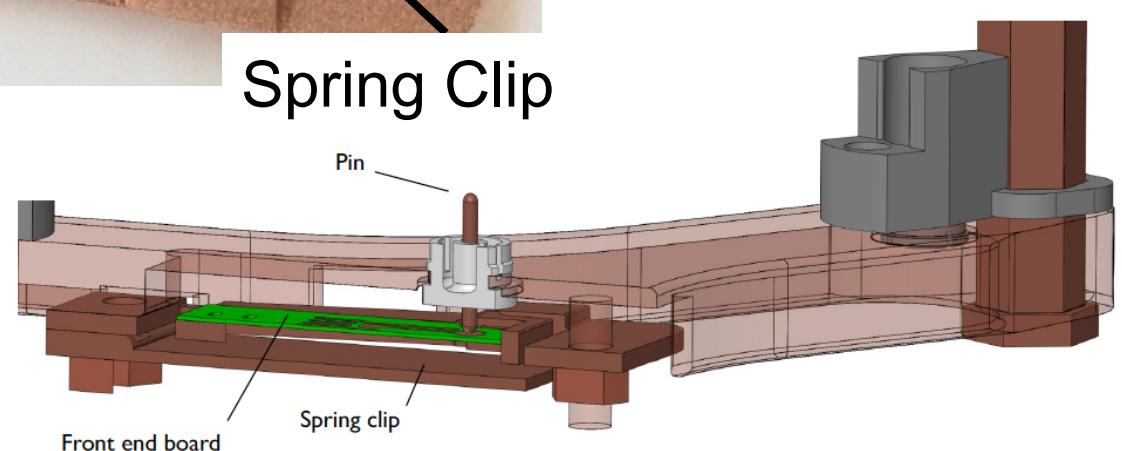
String Assembly



Front-End Board



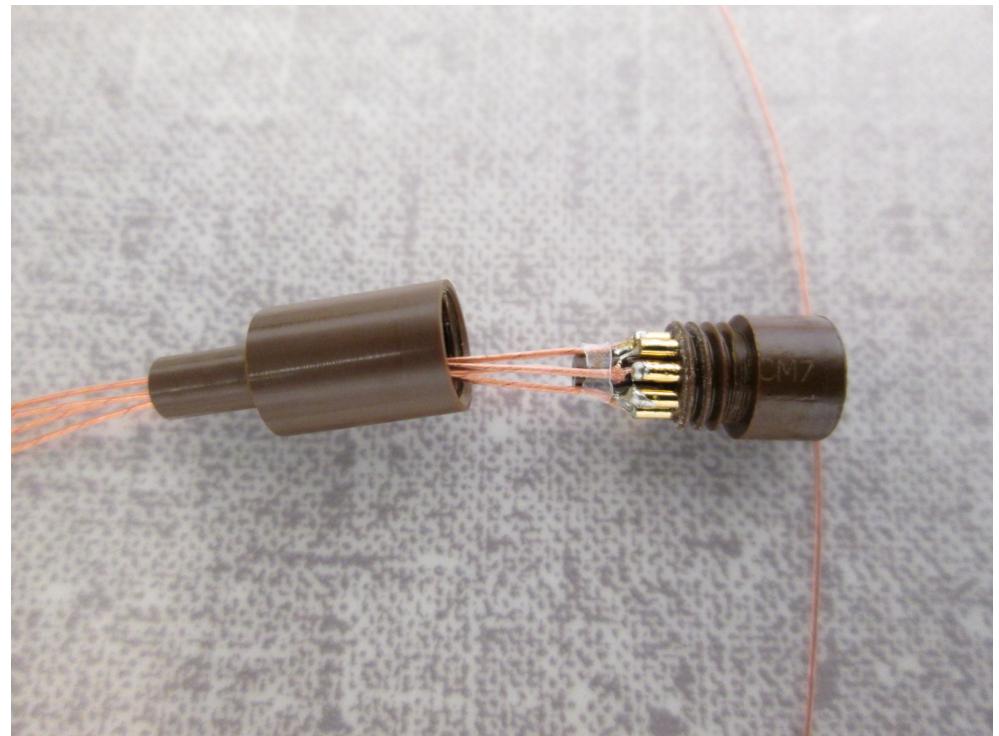
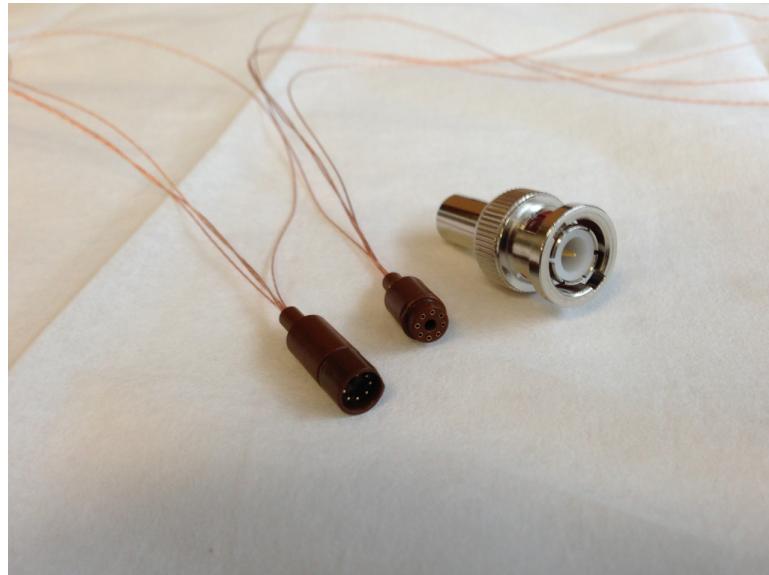
Clean Au+Ti traces on fused silica, amorphous Ge resistor, FET mounted with silver epoxy, EFCu + low-BG Sn contact pin





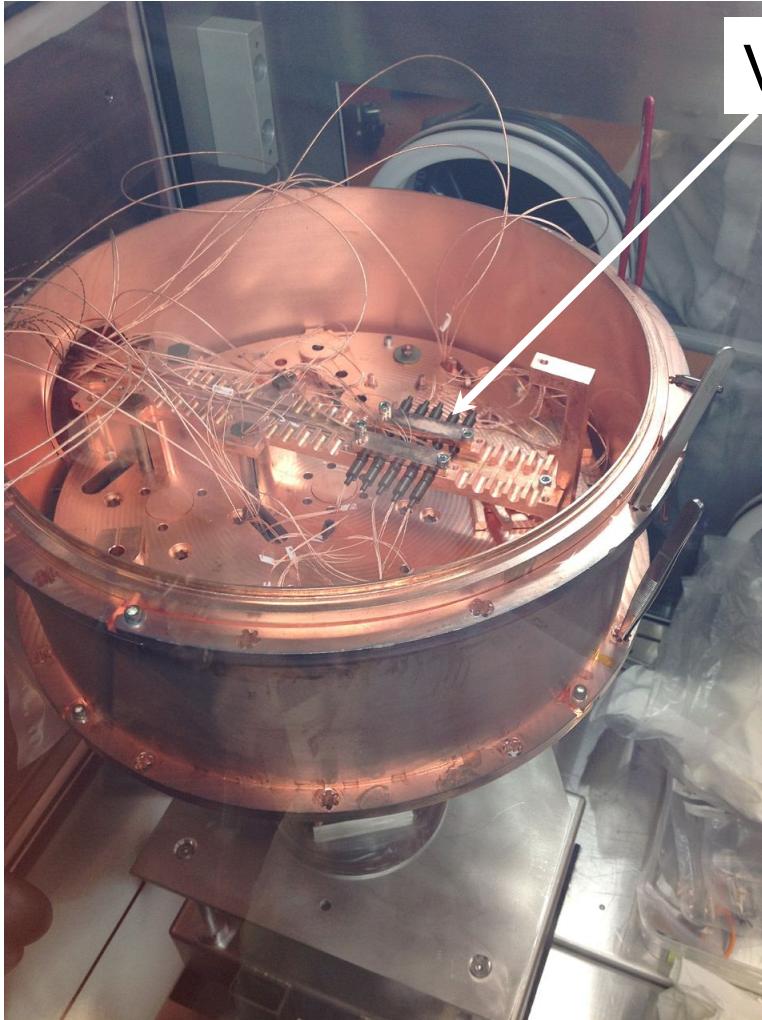
Signal Connectors

Connectors reside on top of cold plate.
In-house machined from vespel. Axon pico co-ax cable.
Low background solder and flux.





Top of the Cold Plate

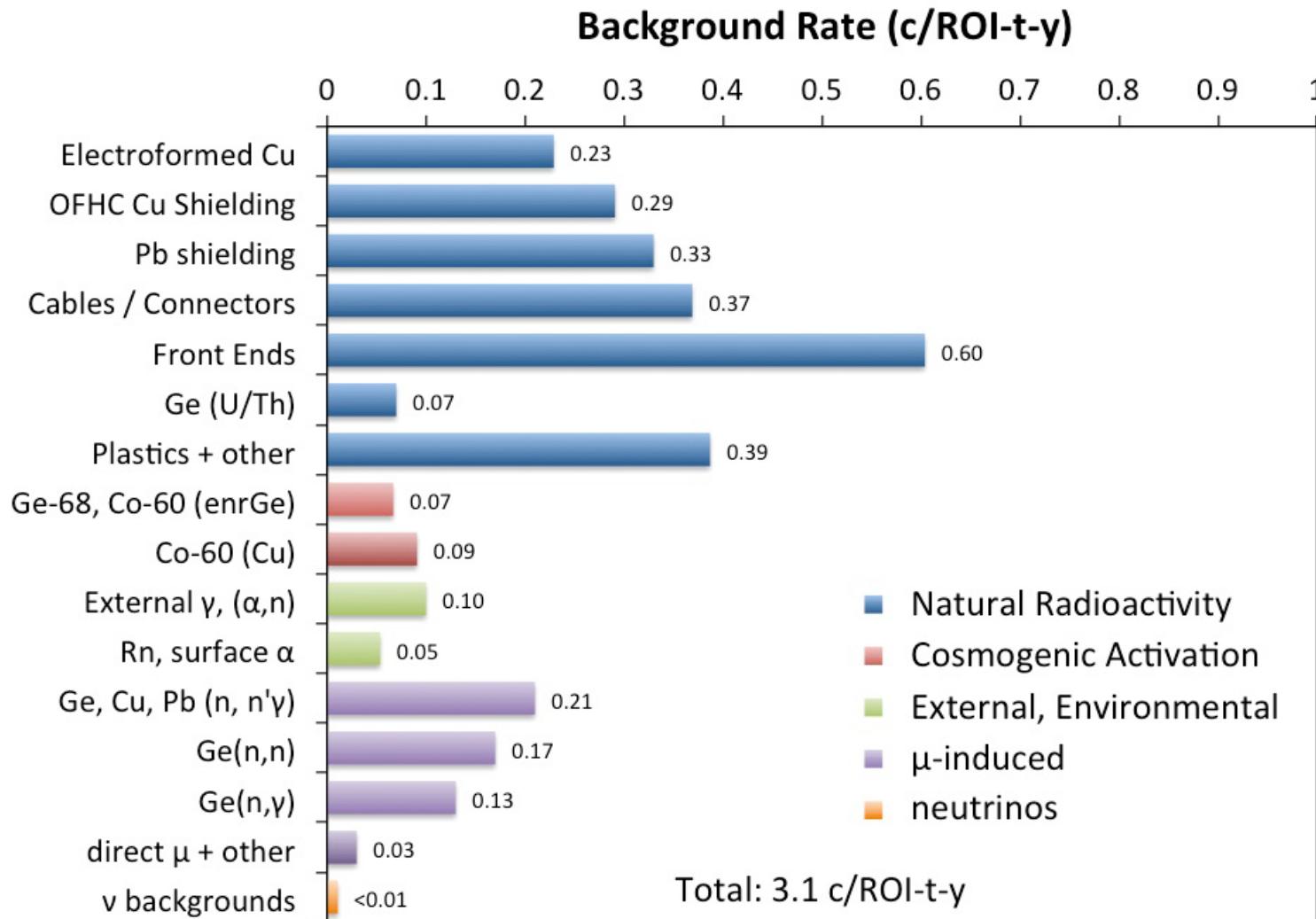


Vespel connectors

HV cables are run from
vacuum feed-through to
detector.



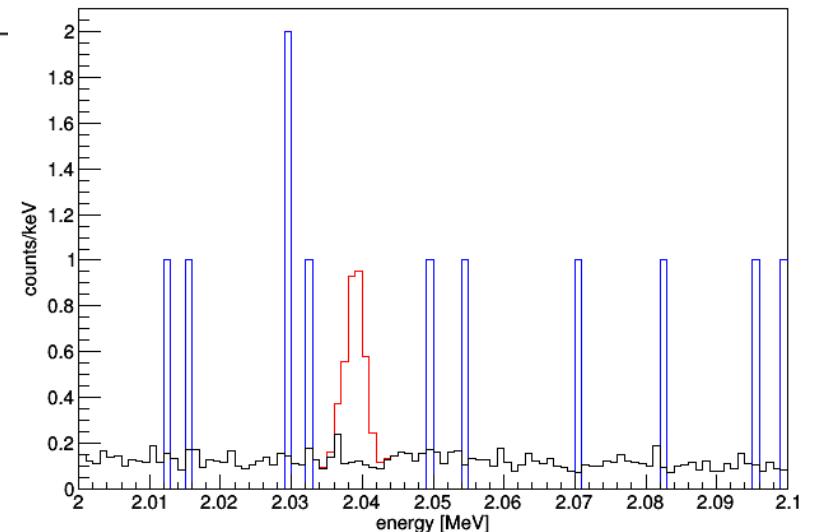
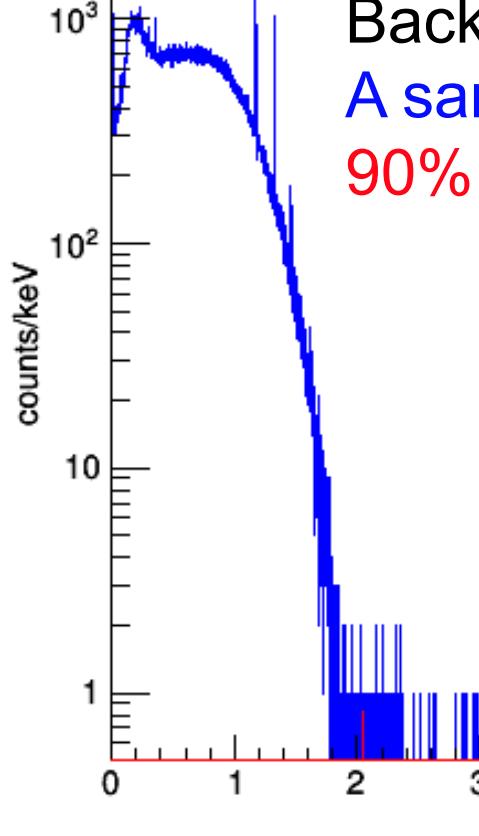
DEMONSTRATOR Background Model





Simulation: MJD 0-10 MeV

MJD, 5-year exposure



MJD Overview



- Assembly and construction proceeding at Sanford Davis Campus laboratory.
- Based on assays, material backgrounds projected to meet cleanliness goals.
- Module 1 complete.
- EF copper just completed at SURF and PNNL.
- Shield nearly complete.
- Successful reduction and refinement of ^{enr}Ge with 98% yield.
- AMTEK (ORTEC) has produced 27 kg within 32 detectors from the reduced/refined ^{enr}Ge . 30 of these are underground at SURF being assembled into strings.

Commissioning Schedule

- Prototype Cryostat – In use
- Cryostat 1 – May 2015
- Cryostat 2 – Late 2015

FNAL, May 2015

Steve Ellic



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The MAJORANA Collaboration



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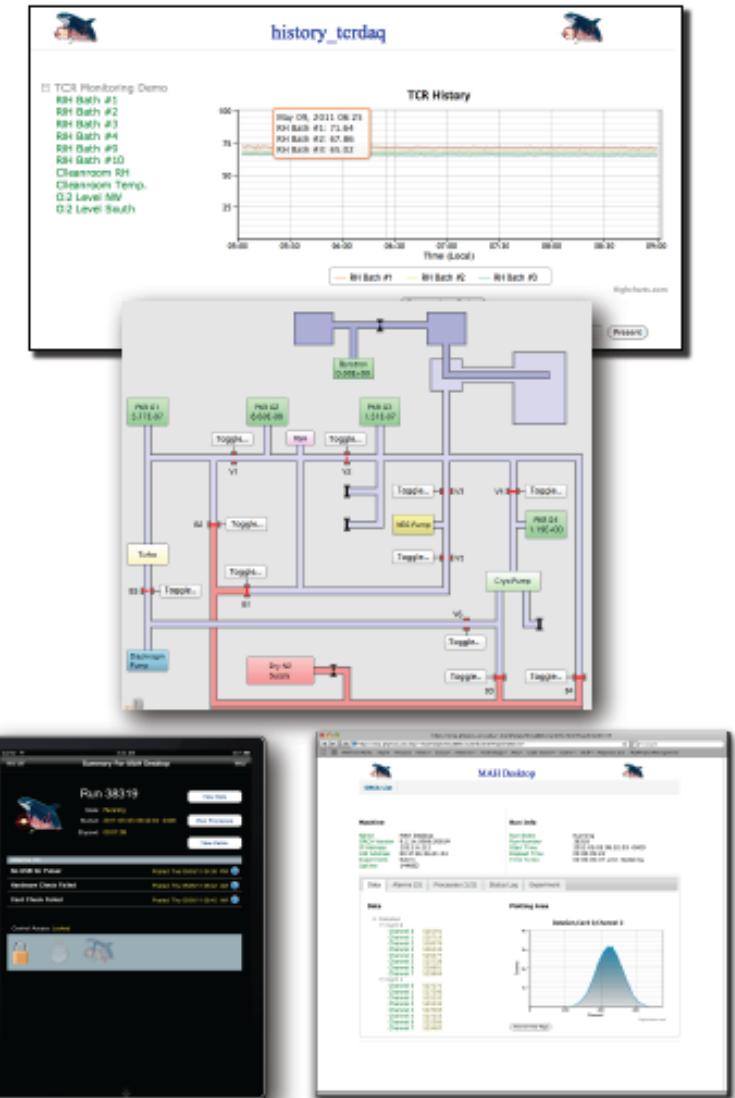
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EXTRAS

Data Acquisition



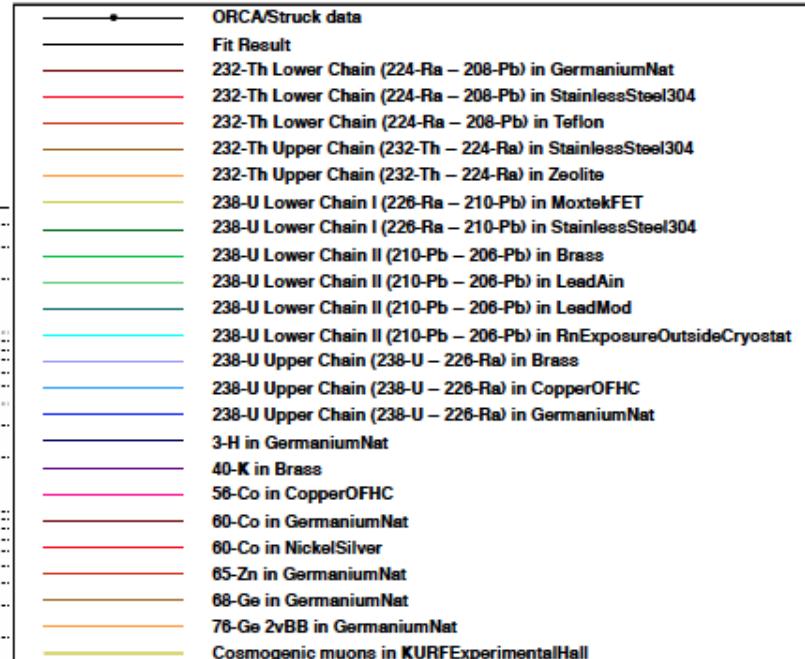
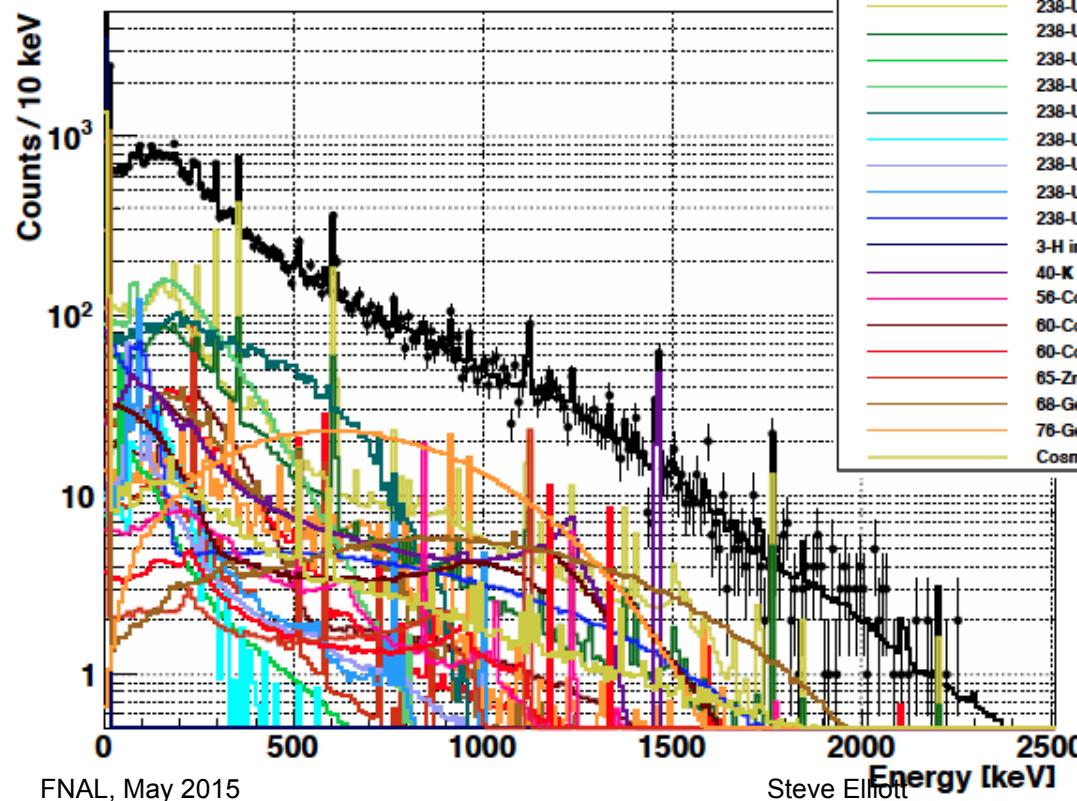
- Slow controls fielded and in operation. Vacuum systems in operation.
- Low sub-keV threshold digital system operating for MALBEK.
- The DAQ software and hardware is up and running and in continuous use for Prototype, test cryostats and detector acceptance testing.
- Tablet and smart phone support.



A full background model has been successfully built for MALBEK using MaGe.
Our simulations of MJD produce the entire spectrum.



50k CPU hours
8k+ runs, 40+ contaminants
56 components, 21 materials



$\chi^2 / \text{DOF} = 97.2 / 114$
P-value = 0.87

A. Schubert,
Univ. Washington,
PhD Dec. 2012

Assay Results



Material	Part of Demonstrator	Decay Chain	Achieved Assay		Reference
			[μ Bq/kg]	[c/ROI/t/y]	
EFCu	Inner Cu Shield, Cryostat, Coldplate, Thermal Shield, Detector Mounts	Th	0.06	0.15	[1]
		U	0.17	0.08	
OFHC	Outer Copper Shield (O.Cut)	Th	1.1	0.26	[2]
		U	1.25	0.03	
Pb	Lead Shield	Th	<4.1	<0.20	[3]
		U	<24.9	<0.26	
PTFE	Detector Supports	Th	0.1 ± 0.01	0.01	[4,5]
		U	<5	<0.01	
Vespel	Cold Plate Supp., Connectors	Th	<12	<0.01	[4,5]
		U	<1050	<0.4	
Parylene	Cu coating, Cryostat seals	Th	2150	0.27	[6]
		U	3110	0.09	
Silica / Au, Epoxy	Front-End Electronics	Th	6530	0.32	[7]
		U	10570	0.28	
Cu Wire + PFA	Signal /HV Cable	Th	2.2	0.01	[8]
		U	145	0.08	
Stainless Steel	Service Body	Th	13000	<0.04	[9]
		U	<5000	<0.03	
Solder Flux	Connectors	Th	365	0.12	Old SNO Report
		U	1157	0.07	

[1] "Determination of Method Detection Limits for Trace 232-Thorium and 238-Uranium in Copper using Ion Exchange and ICPMS-January 2014", [M-TECHDOCPhys-2014-72].

[2] Commercial Copper Assay Report[M-TECHDOCDET-2012-149]

[3] Results of Lead Assay by GDMS; final [M-TECHDOCDET-2012-146]

[4] Final report on assay of plastic for MAJORANA DEMONSTRATOR [M-TECHDOCDET-2011-137].

[5] Report on NAA performed at HFIR (ORNL) for samples of TE-6742 for the MAJORANA DEMONSTRATOR [M-TECHDOCDET-2011-128].

[6] Cable Assay [M-TECHDOCDET-2011-124].

[7] ICP-MS of Low Mass Front-End Board; final [M-TECHDOCDET-2013-157]

[8] ICP-MS Assay of MJD Copper Cables for Uranium & Thorium - December 2013; [M-TECHDOCMJTEST-2014-027].

[9] Service Body Assay Results; final [M-TECHDOCDET-2012-143]

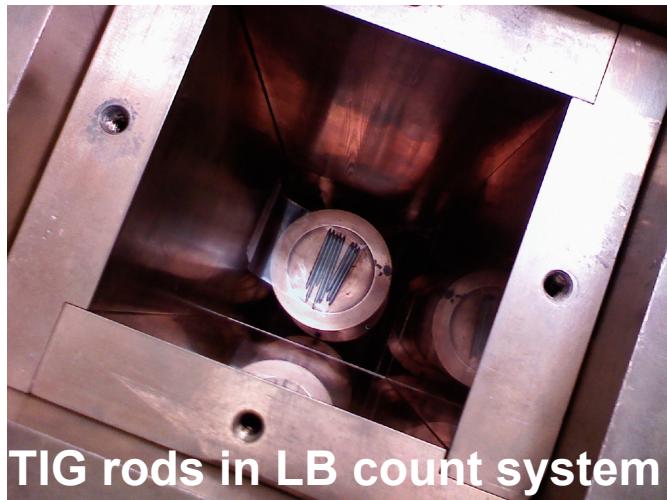


Materials and Assay

- Significant R&D and advances made in improvement of ICP-MS sensitivity for U and Th in copper near $0.1 \mu\text{Bq/kg}$ level.
- Monitoring U and Th in copper baths electrolyte.
- All plastic materials selected after high sensitivity NAA analysis. Assay complete.
- Significant progress made in development of low background front-end electronics.

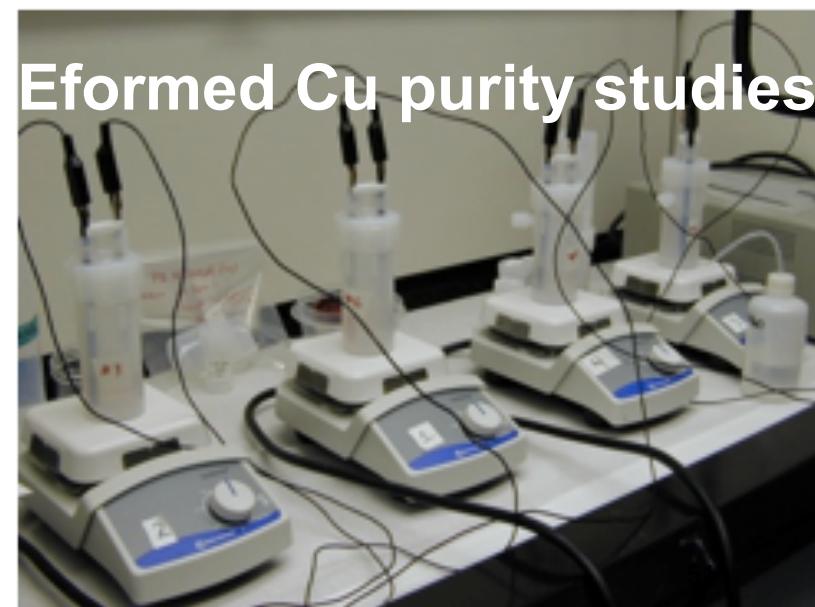


Plastics for NAA analysis



TIG rods in LB count system

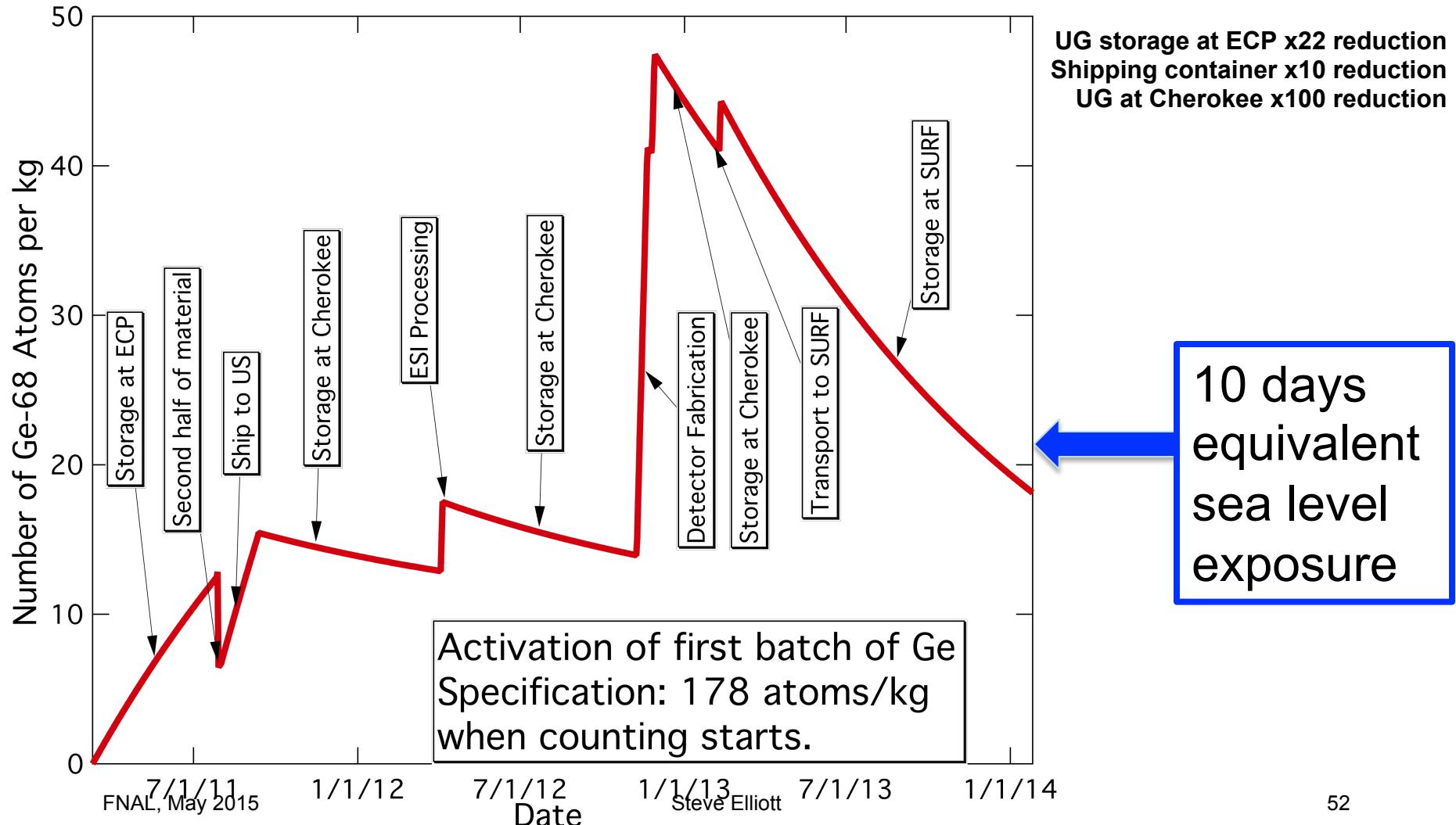
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Eformed Cu purity studies



Enriched Ge Typical Effective Surface Exposure

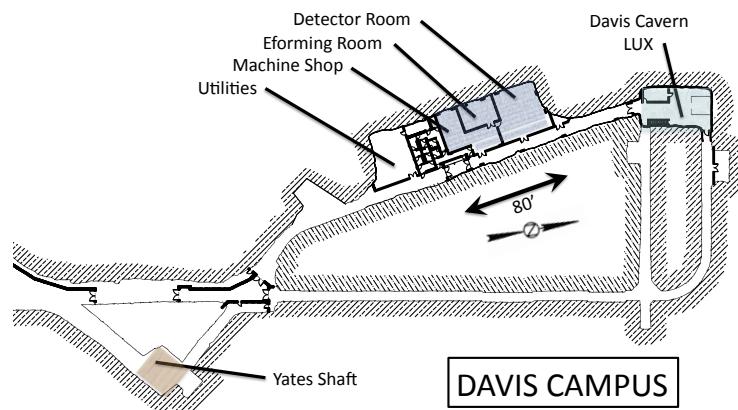




Underground Lab - Status



- Eforming lab operational since 2011
- Davis Campus lab occupied, March 2012
- Shield floor, LN system, assembly table, air bearing system, glove boxes, localized clean space all installed



Steve Elliott



Enriched Ge



- 42.5 kg ^{enr}Ge received as oxide and stored UG in Oak Ridge.
- Processed to metal with >98% conversion.
- Possible additional 4-5 kg Russian contribution.



	Specs	ECP	ORNL Physics (Sample 1)	ORNL CSD (sample 2)	PNNL (Sample 3)
⁷⁶ Ge	≥86.0	87.67	86.9 (2)	87.9 (9)	88.2 (3)
⁷⁴ Ge		12.16	12.5 (1)	12.0 (1)	11.8 (3)
⁷³ Ge		0.07	< 0.2	0.052 (1)	0.04 (2)
⁷² Ge		0.05	<0.2	0.0058 (3)	0.02 (1)
⁷⁰ Ge	≤0.07	0.05	<0.2	0.0157 (3)	0.005 (4)



Neutrino Mixing Parameters

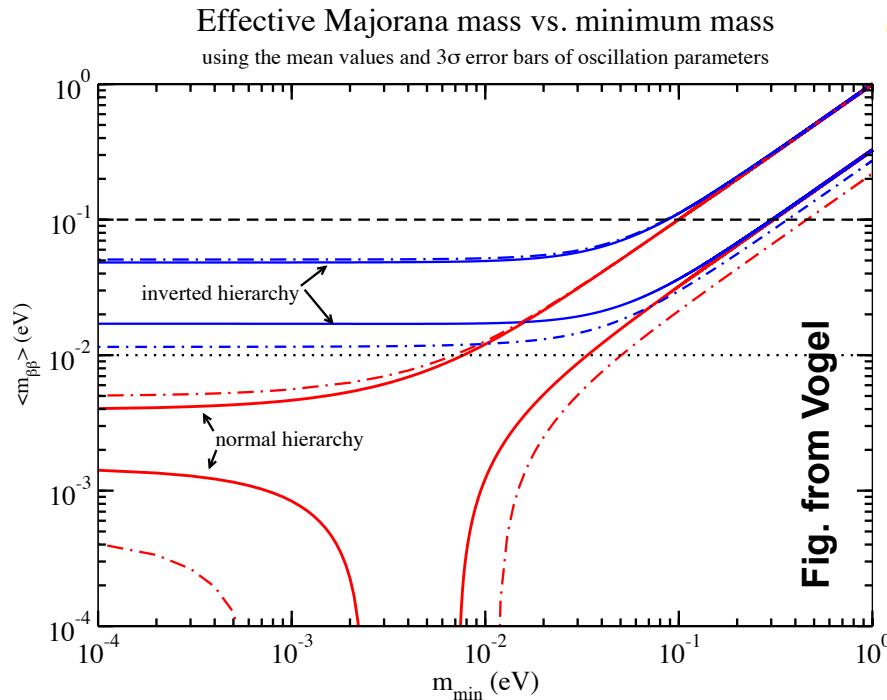


TABLE I: Neutrino mixing parameters from Ref. [3]

Parameter	Best Fit	2σ Range
δm_{sol}^2	75.4 meV^2	$71.5\text{-}80.0 \text{ meV}^2$
δm_{atm}^2	2420 meV^2	$2260\text{-}2530 \text{ meV}^2$
$\sin^2 \theta_{13}$	0.307	0.275-0.342
θ_{13}	33.65°	$31.63\text{-}35.79^\circ$
$\sin^2 \theta_{12}$	0.0244	0.0194-0.0291
θ_{12}	8.99°	$8.01\text{-}9.82^\circ$

To cover inverted hierarchy, must reach about 14.9 meV for $m_{\beta\beta}$.

Matrix Elements

Isotope	NSM	QRPA	IBM-2	PHFB	EDF	$G_{0\nu}$ $10^{-15} /y$
⁴⁸ Ca	0.82-0.90		1.98		2.37	24.81
⁷⁶ Ge	2.81	4.07-6.64	5.42		4.60	2.363
⁸² Se	2.64-3.56	3.53-5.92	4.37		4.22	10.16
⁹⁴ Zr*				2.03		0.680
⁹⁶ Zr		1.43-2.12	2.53	1.45	5.65	20.58
⁹⁸ Mo*				3.37		0.00072
¹⁰⁰ Mo		2.91-5.56	3.73	3.25	5.08	15.92
¹⁰⁴ Ru*				2.35		1.286
¹¹⁰ Pd			3.62	3.85		4.815
¹¹⁶ Cd		2.30-4.14	2.78		4.72	16.70
¹²⁴ Sn	2.62		3.50		4.81	9.040
¹²⁸ Te	2.88	3.21-5.65	4.48	1.62	4.11	0.5878
¹³⁰ Te	2.65	2.92-5.04	4.03	2.21	5.13	14.22
¹³⁶ Xe	1.46-2.19	1.57-3.24	3.33		4.20	14.58
¹⁴⁸ Nd			1.98			10.10
¹⁵⁰ Nd		3.34	2.32	1.62	1.71	63.03
¹⁵⁴ Sm			2.50			3.015
¹⁶⁰ Gd		3.76	3.62			9.559
¹⁹⁸ Pt			1.88			7.556
²³² Th						13.93
²³⁸ U						33.61

Factors of ~2 variation for each isotope – factor of 4 in required exposure.

Axial Vector coupling constant appears as 4th power – big effect

- In β -decay, the theoretical matrix elements are larger than the experimental ones. The ratio is nearly constant, so to account for this, the value of g_A is “quenched” by a factor of about 0.8.
- The level of quenching will depend on the number single particle states included in the shell.
- In $2\nu\beta\beta$, quenching is also observed and how much is required depends on the configurations used in the calculation. Calculations tend to find a g_A near 1.0, instead of 1.27 works best. In some comparisons (e.g. IBM-2) between matrix elements and measured rates, the result gives $g_A \sim 0.6$. This is a factor of $2^4=16$ in the required exposure.
- Is quenching required in $0\nu\beta\beta$?
- $2\nu\beta\beta$ only connects 1+ states in intermediate nucleus, whereas $0\nu\beta\beta$ connects a large number of states. The $2\nu\beta\beta$ momentum transfer is a few MeV, whereas for $0\nu\beta\beta$ it is about 100 MeV. Big difference in operator expansions.
- Unlike $2\nu\beta\beta$, $0\nu\beta\beta$ has a Fermi matrix element in addition to Gamov-Teller. The Fermi part does not include quenching, hence although still a big effect, its not as big for $2\nu\beta\beta$.
- Other processes, such as mu-capture, that involve all such states and has a similar momentum transfer don't require quenching. If quenching is present, it is unlikely to be as large as in the $2\nu\beta\beta$ case. Question certainly needs further study.

Phase Space Factors, Other $\beta\beta$ Mechanisms

- $G_{0\nu}$ is known to about 7%, where the uncertainty comes from the uncertainty in the input parameters.
(Katila/Iachello, PRC 85, 034316 (2012)) Calculations differ depending on isotope by about 1-2% (Stoica/Mirea arXiv: 1307.0290).
- We know that light neutrinos exist, so it seems plausible to focus on that mechanism.
 - However it is, in principle, possible that more than one mechanism exists and contribute at a comparable level and interference might be present.
 - Such an interference seems a bit unnatural and it seems likely that one mechanism will dominate.